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# TECHNICAL CONSIDERATIONS FOR IMPROVEMENT OF USAF OPERATIONAL TRAINING, TESTING AND EVALUATION (OTT&E)

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| Targets | Range Improvement | |
| Communications | Technical Considerations | |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This Guide discusses the technical considerations for the improvement of USAF ranges. Major range segments include targets, threats, TSPI, communications, command/control, and range support. This report is one of a seven volume set of documents which together form a generalized guide for the improvement of USAF Operational Training, Testing and Evaluation (OTT&E). These volumes document analyses of OTT&E requirements, categorize the requirements into generalized mission scenarios, review the technical considerations for OTT&E evaluations, examine the influences of intelligence information on the validity

of OTT&E, survey the characteristics of available OTT&E range systems, present equipment selection information, and outline improvement processes and procedures. The Specific volumes are:

| TESPO # | |
|---|---|
| 2FTP-H0386001 | Guide for Improvement of USAF OTT&E |
| 2FTP-H0386002 | Requirements Analysis for Improvement of USAF OTT&E |
| 2FTP-H0386003 | Technical Considerations for Improvement of USAF OTT&E |
| 2FTP-H0386004 | Intelligence Considerations for Improvement of USAF OTT&E |
| 2FTP-H0386005 | Survey and Information for Selection of TSPI System for USAF OTT&E |
| 2FTP-H0386006 | Survey and Information for Selection of Ground Targets for USAF OTT&E |
| 2FTP-H0386007 | Survey and Information for Selection of Threat Simulators for USAF OTT&E |

2FTP - H0386003


## ABSTRACT

In undertaking the development and acquisition of improved training, testing and evaluation (TT&E) equipment/facilities, it is essential that the starting point, incremental growth, and the fundamental technical precepts be established and understood from the onset. This document identifies and discusses each of those considerations which transcend the major elements of the overall improvement program and the efforts necessary to obtain the highest priority capabilities summarized in the companion document, "Requirements Analysis for Improvement of USAF OTT&E," 2FTP - H0386002. The contents will both document the basis for courses chosen and serve as a considerations guide for future improvement programs. The systems engineering and management approaches in use should assure a balanced treatment of all requirements and disciplines in the extensive trade-offs needed to satisfy budget constraints as set forth in another companion volume, "Guide for Improvement of USAF OTT&E," 2FTP - H0386001.

## RELATED DOCUMENTS

This report, "Technical Considerations for Improvement of USAF OTT&E," is one of seven documents which together form a generalized guide for the improvement of USAF Operational Training, Testing and Evaluation (OTT&E). These volumes document analyses of OTT&E requirements, categorize the requirements into generalized mission scenarios, review the technical considerations for OTT&E evaluations, examine the influences of intelligence information on the validity of OTT&E, survey the characteristics of available OTT&E range systems, present equipment selection information, and outline improvement processes and procedures. The specific volumes are:

| TESPO # | |
|---|---|
| 2FTP-H0386001 | Guide for Improvement of USAF OTT&E |
| 2FTP-H0386002 | Requirements Analysis for Improvement |
| 2FTP-H0386003 | Technical Considerations for Improvement of USAF OTT&E |
| 2FTP-H0386004 | Intelligence Considerations for Improvement of USAF OTT&E |
| 2FTP-H0386005 | Survey and Information for Selection of TSPI Systems for USAF OTT&E |
| 2FTP-H0386006 | Survey and Information for Selection of Ground Targets for USAF OTT&E |
| 2FTP-H0386007 | Survey and Information for Selection of Threat Simulators for USAF OTT&E |

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# TECHNICAL CONSIDERATIONS FOR IMPROVEMENT OF USAF TRAINING, TESTING & EVALUATION

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# SECTION 1

# GENERAL CONSIDERATIONS

## 1.1 PROGRAM CONSIDERATIONS

The objective of the TT&E Improvement Program is to establish a continuing integrated program to improve the testing/training capabilities at existing USAF air-to-ground, air-to-air, and radar bomb scoring sites and ranges. As this is envisioned to be a continuing program over an extended time frame, the technical approach requires an evolutionary development and acquisition process at each stage of capability increase to avoid scrapping existing capabilities as new capabilities are added.

## 1.2 OPERATIONAL CONCEPT

Each Air Force range or site has unique characteristics, limitations, requirements and missions. Therefore, separate operational concepts are needed for each range that requires improvements. Current range/site owners will continue to operate and maintain their facilities throughout the improvement cycle. Range improvement equipment should be turned over to the range owner after the required integration and testing has been completed. Normally, the range owners/operators provide the necessary interface with other local airspace, land and frequency spectrum users.

## 1.3 DEVELOPMENT AND ACQUISITION APPROACH

The approach is a careful application of established procedures and disciplines to major phases of effort: requirements, design, fabrication, installation, and checkout test and evaluation to validate/confirm/verify the system capability and identify limitations. The requirements are established in a broad sense by the operating and using commands and are defined in more specific detail through mission analyses by both the developer and operator/users.

Validation of the operational requirements occurs prior to issuance of the directive to proceed. The companion document 2FTP - H0386002 has been developed after considerable interface with the range operators/users. This family or class of requirements should be validated by USAF so specific items of equipment may be programmed and procured annually as the budget will allow. After validation, the engineering definition and trades should be well along before initiation of procurement actions. Solutions should be selected in the following order of precedence: Existing systems and equipment, existing designs, programmed systems and equipment and developments based on the state-of-the-art technology.

## 1.4 SYSTEM ENGINEERING

From the general and specific directives and detailed mission analyses, requirements can be derived to serve as inputs to the performance specifications needed for the procurement of hardware/software. For acquisition purposes, the TT&E Improvement Program can be conveniently divided into six hardware-oriented areas or segments. These are:

a. Simulated Enemy Threats.

b. Targets.

c. Instrumentation.

d. Command and Control.

e. Communications.

f. Range Support Facilities.

For procurement purposes, a series of specifications will be required for:

a. TT&E Improvement Systems.

b. TT&E Segments.

c. TT&E Interfaces.

d. TT&E End Items.

During development and acquisition, formal design and configuration reviews are necessary to insure progress and achievement of performance and functional objectives. Figure 1-1 illustrates the system engineering flow process.

## 1.5 VALIDATION/VERIFICATION/LIMITATION

Included in the acquisition process is a series of equipment and systems tests needed to assure that objectives are achieved in terms of capability as well as the definition of limitations. Test responsibilities must be defined in specific test objective documents for each segment, system or end item. To assure achievement of the range capability sought, the operator will normally participate in the final DT&E/IOT&E to establish satisifaction of the Government prior to the system being declared ready for turnover and transition. With these processes described in detail elsewhere, this document concentrates on a detailed technical approach for the program. Figure 1-2 shows the validation/verification/limitation flow of a system.

## 1.6 SUMMARY

Section 2, "Basic Evaluation Concepts," presents basic evaluation concepts and provides rationale for the Training, Testing and Evaluation (TT&E) Improvement Program. The process of translating operational requirements into instrumentation requirements is also discussed.

Section 3, "Training, Testing and Evaluation Improvement Process" presents the objectives of the Training, Testing and Evaluation Improvement Program, the operational characteristics common to all ranges selected for improvements, and a description of the improvement program segments.

Section 4, "Technical Considerations," provide a detailed technical description of the particular techniques, procedures, and equipment required to provide improved TT&E capabilities.

The planning reflected by this document is based on the following:

## SIMPLIFIED SYSTEMS ENGINEERING

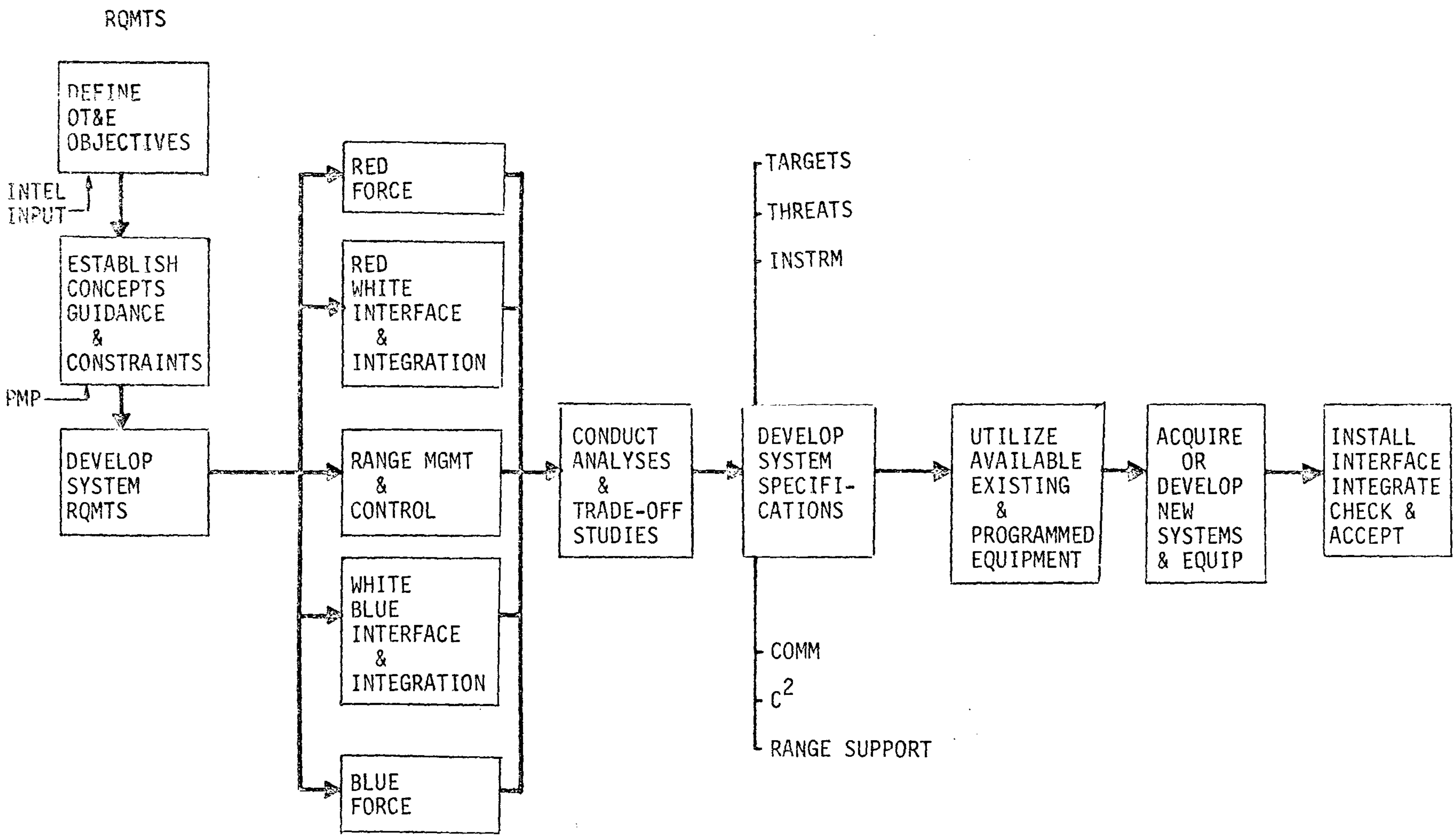
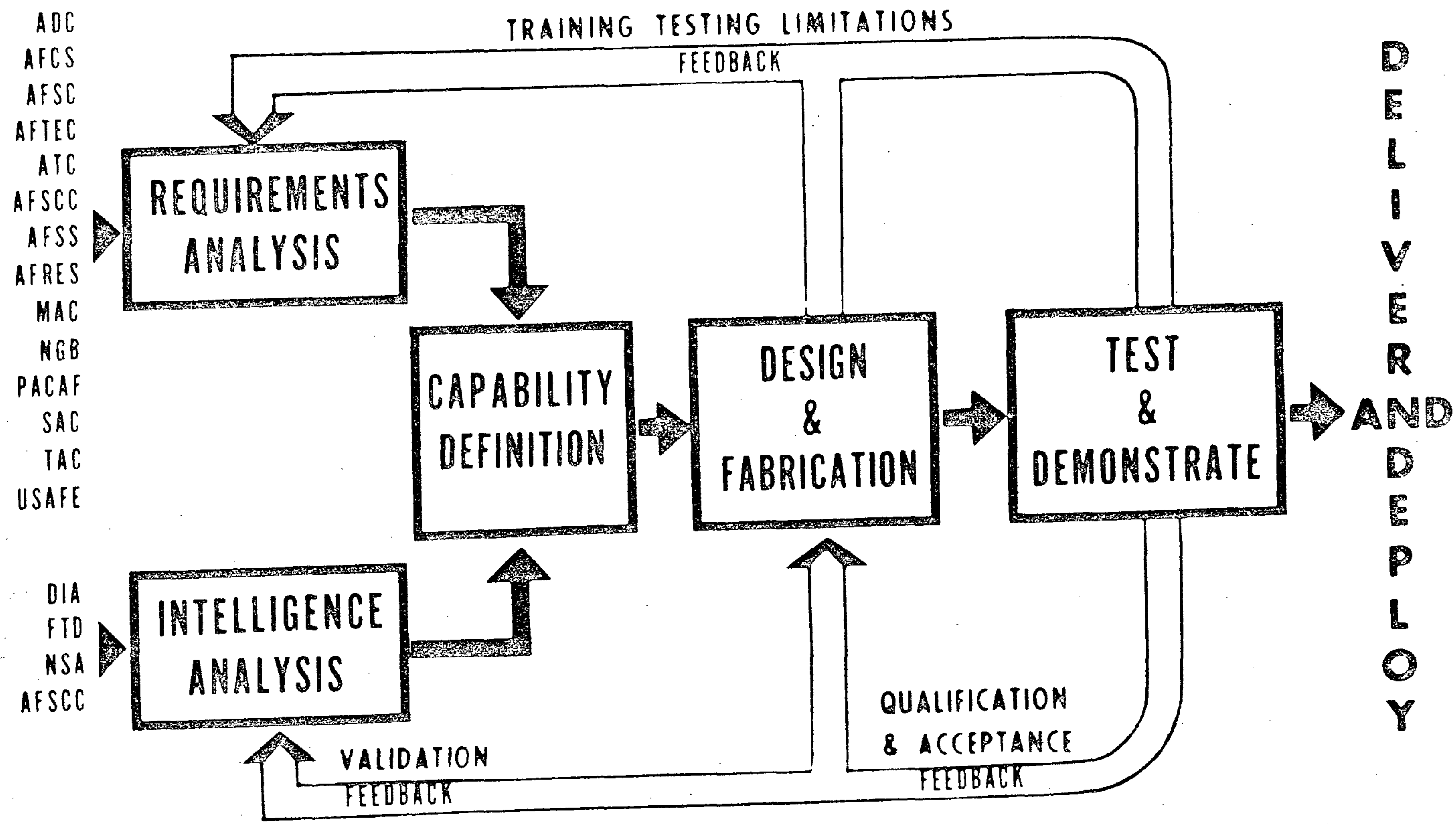



FIGURE 1-1

# VALIDATION/VERIFICATION/LIMITATION




OPERATIONAL COMMANDS | DEVELOPMENT & ACQUISITION ORGANIZATION

INTELLIGENCE AGENCIES | TESPO

Figure 1-2

a. The stated objectives and priorities of existing directives to improve USAF Training, Testing and Evaluation.

b. Requirements set forth in "Requirements Analysis for Improvement of USAF OTT&E," 2FTP -H0386002.

c. Review and analysis of the real-world, time-phased threat situation presented in the related document, "Intelligence Considerations for Improvement of USAF OTT&E," 2FTP - H0386004.

d. Established operational, technical and support constraints, plus the "Design to Constraints of Budget, Cost, or Life Cycle Cost."

# SECTION 2

# BASIC EVALUATION CONCEPTS

## 2.1 PERFORMANCE MEASURES

A fundamental ingredient of military test and training operations is to obtain quantitative indicators of "performance," in terms which are sensitive enough to detect meaningful differences in performance among competing equipments or alternative tactics. However, "performance" is difficult to quantify in operational terms. For example, an instrumentation device cannot directly measure "suitability," "effectiveness," "adequacy," "survivability," etc., since these are basically qualitative terms. Instrumentation can, however, measure physical quantities (such as position, velocity, acceleration, event timing, error values, antenna gain, etc.). These physical measurements may be summarized by statistical or mathematical descriptors (such as mean time between failures, circular error probability, side-lobe ratio, etc.). These in turn may be used directly or via mathematical models to project corresponding descriptors under operational conditions, which can provide the basis for judgments concerning suitability, adequacy, etc. Because effectiveness per se cannot be measured, it is necessary to decide upon a set of measurable quantities (or summarizers of them) which can give a quantitative character to "effectiveness." Some of the ingredients involved in the effectiveness assessment are shown in Figure 2-1.

The problem of selecting a set of useful measurable quantities which also satisfy the conditions of sensitivity and operational pertinence becomes especially acute when "performance" judgements are required with respect to multiple participants in a two-sided encounter. Figure 2-2 identifies some of the numerous potential crew errors in a multiple participant situation which can influence a mission's effectiveness. In particular, there is an understandable hesitance to judge performance from the same set of measurable quantities which have been used as a basis for judgments in simpler (one-on-one)

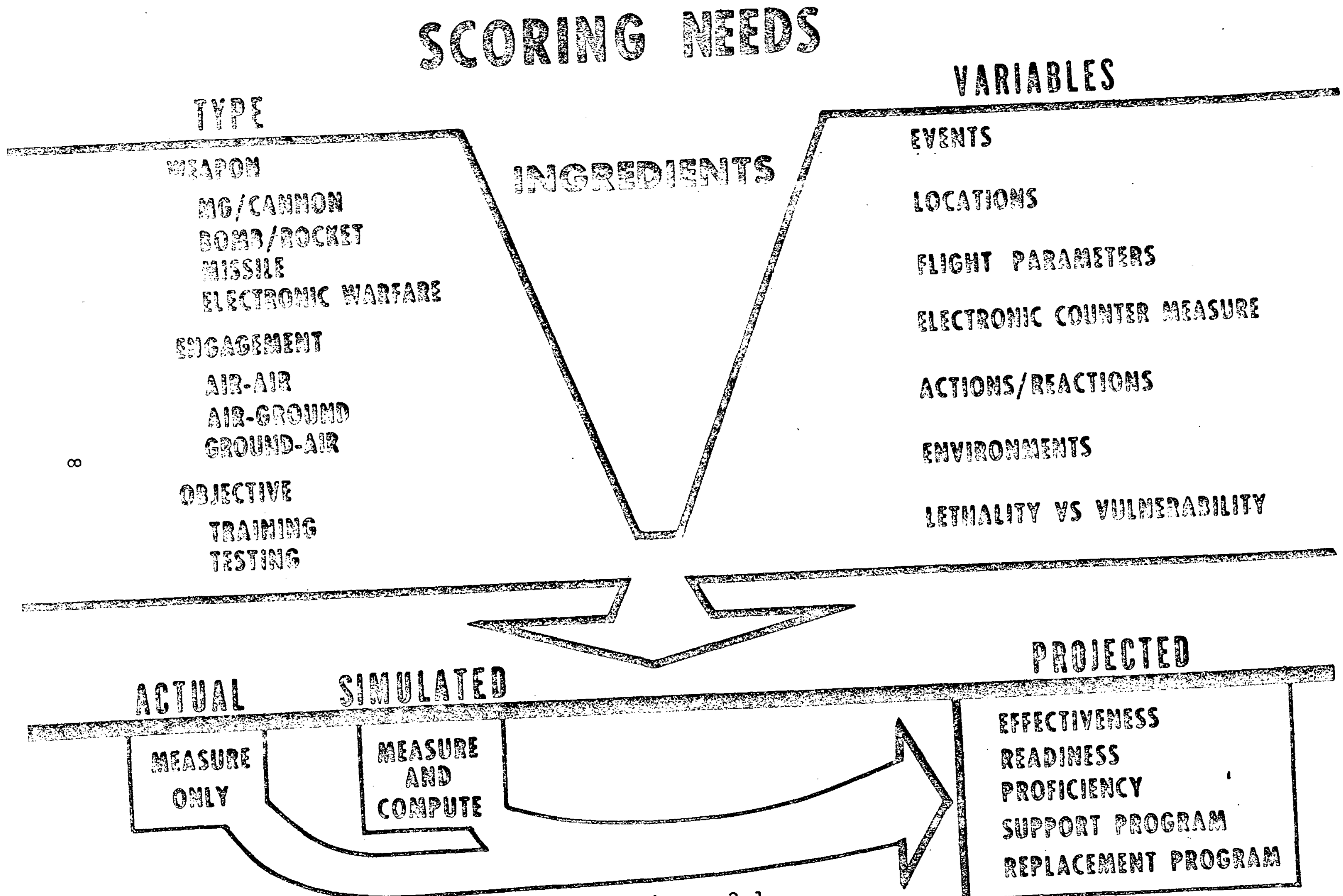

SCORING NEEDS
TYPE
WEAPON
MG/CANNON
BOMB/ROCKET
MISSILE
ELECTRONIC WARFARE
ENGAGEMENT
AIR-AIR
AIR-GROUND
GROUND-AIR
OBJECTIVE
TRAINING
TESTING
INGREDIENTS
VARIABLES
EVENTS
LOCATIONS
FLIGHT PARAMETERS
ELECTRONIC COUNTER MEASURE
ACTIONS/REACTIONS
ENVIRONMENTS
LETHALITY VS VULNERABILITY
ACTUAL
MEASURE ONLY
SIMULATED
MEASURE AND COMPUTE
PROJECTED
EFFECTIVENESS
READINESS
PROFICIENCY
SUPPORT PROGRAM
REPLACEMENT PROGRAM

Figure 2-1

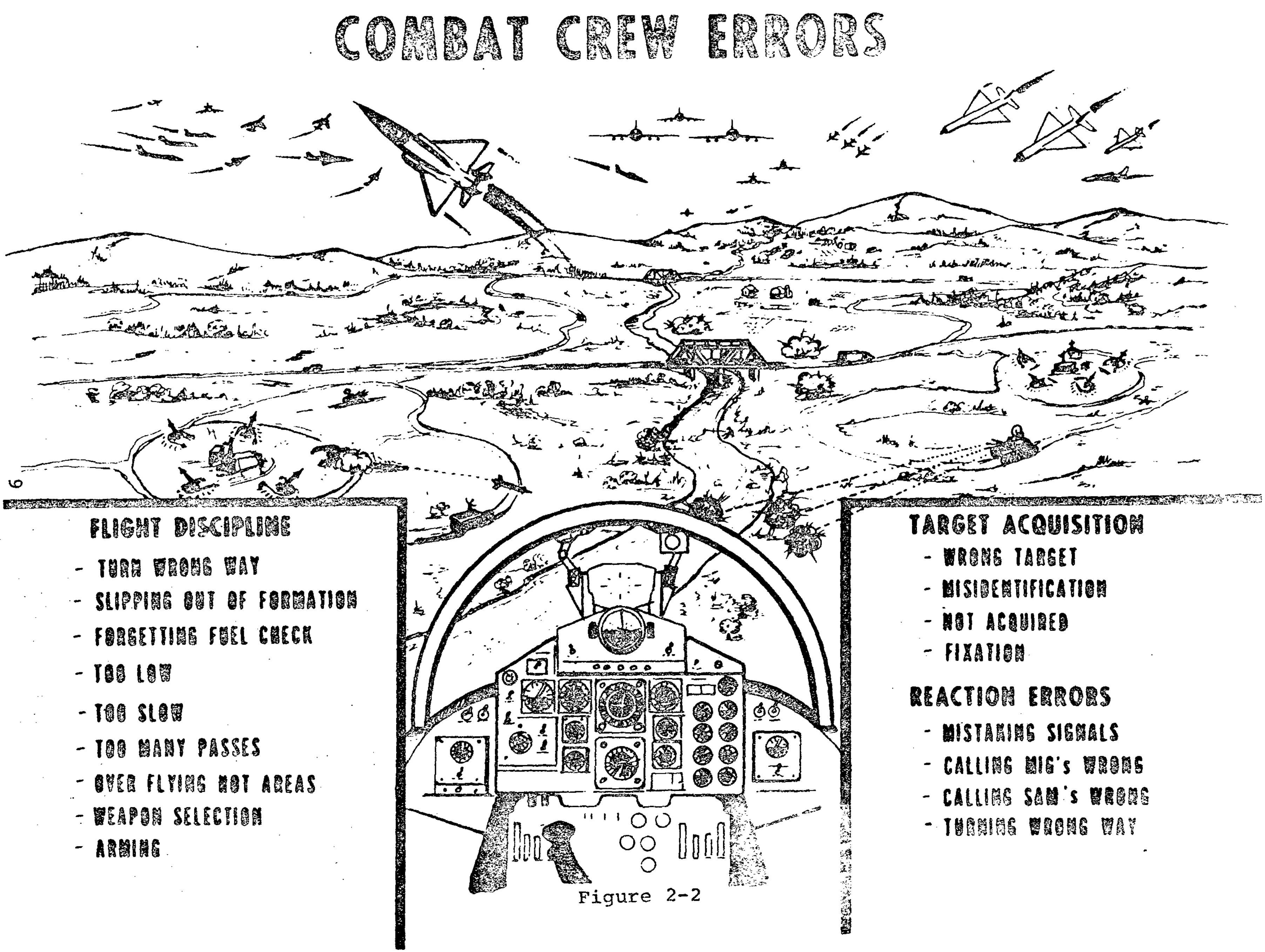

COMBAT CREW ERRORS
FLIGHT DISCIPLINE
- TURN WRONG WAY
- SLIPPING OUT OF FORMATION
- FORGETTING FUEL CHECK
- TOO LOW
- TOO SLOW
- TOO MANY PASSES
- OVER FLYING HOT AREAS
- WEAPON SELECTION
- ARMING
TARGET ACQUISITION
- WRONG TARGET
- MISIDENTIFICATION
- NOT ACQUIRED
- FIXATION
REACTION ERRORS
- MISTAKING SIGNALS
- CALLING MIG's WRONG
- CALLING SAM's WRONG
- TURNING WRONG WAY

Figure 2-2

situations. This hesitancy is in some sense attributable to the large number of descriptors which the evaluator would be required to assimilate and weigh in coming to a judgment, but the major source of concern is a sense of the inappropriateness of such extension to multiple-participant encounters. This uneasiness is even more pronounced when the evaluator must infer what would happen in a multiple participant encounter on the basis of data taken in a one-on-one test, and often mamifests itself in the form of a special mistrust of mathematical models or simulators which attempt to accomplish such extensions and projections.

Bypassing these problems and examining the end results of a conflict, "performance" can be characterized in terms of the number of casualties (or survivors) in a military encounter. It is informative to measure "casualties" in units of equipment (aircraft, SAM sites, primary targets) rather than personnel. Such a descriptor certainly possesses the attributes of quantifiability, sensitivity, and pertinence. It also has merit as an absolute measure of readily understandable significance, in addition to its obvious utility as a relative measure, or discriminator, among alternatives. However, its greatest appeal lies in its unversality: "What is the value of this new training method? Of this new jammer? Or this new tactic? Or this new airplane?" Can all be answered by showing how aircraft losses were lessened, while accomplishing the same mission, as compred to the old training method, jammer, tactic, or airplane?

Such an attractive scheme for characterizing performance does not come easily. As might be expected, there are important prices to be paid (not only in monetary terms) in order to attain this goal. One of the most important ways in which the cost is expressed is in the critical importance of realism as a necessary ingredient of the test situation. Realism of replications of enemy equipment, command and control structure, employment doctrine and tactics, as well as the corresponding aspects of the friendly forces attacking or penetrating this defensive network is of key

importance; since one of the major justifications for the "end result" type of performance measure is mistrust of complex mathematical models. An especially important aspect of necessary realism is the provision for the nearly instantaneous "removal" (by procedural means) of "killed" participants from the encounter, because their unrealistic continued participation, even for very short intervals, could wrongly affect the end result.

However, a "safe" war game is unrealistic in some basic and irremediable ways. Because lethal weapons cannot actually be fired in two-sided encounters involving human participants, there can be no opportunity to react to the sensing of actual missile trajectories in real time. For example, there can be no aircrew reaction to a surface-to-air missile in flight by virtue of continued visual contact, which could be important for controlling evasive maneuvers, when such a missile is "flying" only internally in a computer mathematical simulation. On the defensive side, there will be no opportunity for a defensive radar crew to detect that a simulated anti-radar missile has been launched against it, requiring suitable counteraction, such as shutting down the radar and/or activating a decoy. Because training/test ranges must necessarily exploit sparsely inhabited areas sometimes referred to as wasteland, the defensive systems cannot be realistically deployed in and around industrial and metropolitan centers as would normally be the case.

However, in full awareness of the limitations and risks attending these concepts, such methods for characterizing performance in complex, multiple-participant engagements are so superior to any other alternative which can be posed, that implementation on certain Air Force test/training ranges is clearly desirable.

A problem of a different sort is presented with respect to the necessary time-phased implementation of TT&E improvements. While an argument can be presented for the value of a "realistic"

enemy threat deployment alone as a vehicle for training, the complete characterization of the results of encounters between such an environment and multiple penetrators in terms of the casualties or survivors will not be achieved in the near future. This, then raises the reasonable question, "Is there a sensible half-way point for TT&E improvements, which provides a utility commensurate with its investment, short of a completely credible simulation of equipment guidance, fuzing, warhead lethality, and aircraft vulnerability necessary for believable "kills" in real time?"

The answer to this question must come from the development of less sophisticated performance descriptors which can be supported by instrumentation and scoring techniques which can be made available in the near future. The practical necessity for these performance descriptors in the intermediate phases adds urgency to the current effort to survey the potential needs of range operators and users in these early time frames, and translate those needs into acceptable (if not ideal) performance measures of utility.

## 2.2 INTERPRETATION OF OPERATIONAL REQUIREMENTS

None of the guidance and directive documents for the TT&E Improvement Program furnish a solid supporting rationale to show how the detailed requirements for values to be measured and their accuracies are derived from the statements of broad mission categories or types of training/testing to be supported. In particular, there is no indication of "performance measures" or "performance descriptors" which will characterize how well a training mission, test, air-to-air encounter, etc., is accomplished. The "casualty list" performance descriptor discussed in paragraph 2.1 above is not explicitly identified as a goal for TT&E improvements. However, the capability to evaluate the worth of a particular piece of equipment or tactic employed against any portion of a realistic environment is enhanced by the ability to perform real time casualty

assessments. Meanwhile, before this capability can be implemented, a logical structure which has as its central theme a set of performance descriptors will be developed. This structure of performance measures is not viewed as an abstract exercise, but as the central element of a necessary formal justification for the investment in particular items of hardware, and as a basis for a "systems approach" to the stage-by-stage growth of TT&E improvements. The formulation of this set of specific performance descriptors and coordination with range operators/users with respect to the value of such descriptors in characterizing performance for specific test or training missions can provide the vehicle for assessing the utility of TT&E improvements to range users, and will furnish an organized basis for decisions on funding and schedule which impact that utility.

To give an example, electronic warfare effectiveness can be characterized by a descriptor such as the ratio of total defense tracking time (by fire control AAA radars or SAM radars) to the total exposure time of the attackers to these radars. Obviously, the terms "tracking" and "exposure" require precise definition. Some systems have a lock-on relay which could define tracking time electrically and unambiguously. Exposure can be defined with respect to the engagement volume of the defensive weapons and specified geometrically. The specific items of data needed to permit the calculation of this proposed performance descriptor are:

a. The time of closing and opening of the lock-on relay (or equivalent events for all defensive fire control and SAM guidance radars).

b. Times of entry and exit of the specified engagement volumes.

The second set of data items implies a requirement for a knowledge of the time/position history of participating aircraft, so that the times of crossing the geometric boundaries of the engagement region of the defensive

weapons can be determined. Such a performance measure is certainly achievable with the kinds of equipment available today. It is quantitative, reasonably sensitive to changes in electronic warfare equipment and tactics, and is pertinent, at least for noise jamming. It would not be pertinent (nor sensitive, probably) to various types of deception jamming. In such cases, other descriptors would be necessary to indicate "how well" the deception worked. Recognizing such limitations the question to resolve becomes, "Is this postulated performance measure (i.e., the ratio of track time to exposure time) sufficiently useful for some test or class of tests which has been programmed for the near-term period to warrant its implementation (i.e., the acquisition of the instruments required to measure and record the data items necessary for the calculation of that performance descriptor)?" If coordination with users results in an affirmative answer, acquisition of the necessary equipment is tied directly to a needed capability expressed in terms of measurements necessary to describe performance.

The example given above is overly simplistic. However, such a technique permits the translation of broad and general statements of requirements into specific questions concerning the particular elements of data which are needed to describe performance. From the necessary data elements, the specification of instrumentation to measure and acquire them can follow in a straight-forward manner.

Ideally, the specification of measurement devices should be preceded by the framing of questions regarding requirements by the specific and organized way described above, and by the coordination cycle with range operators/users including the consolidation of an "agreed" list of performance descriptors and the data items required or implied by them. Necessarily, some estimates based on experience must be used to pose an initial framework for the specification and selection of hardware, in order that this planning for equipment acquisition can proceed in parallel with

the performance-measure definition processs described above. This emphasizes the urgency of the detailed requirements-refinement process during development, acquisition and use. As the requirements evolve with the application of new systems, weapons and tactics, the older methods of TT&E will, in many areas, become less adequate. In fact the TT&E needs of new systems should be an inherent part of those systems, developed concurrently instead of with today's separate and often uncoordinated development.

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# SECTION 3

## TRAINING, TEST AND EVALUATION IMPROVEMENT PROCESS

### 3.1 OBJECTIVE

The primary objective of a TT&E improvement effort is to establish a continuing, integrated program to provide improved capabilities for conducting training and testing operations at existing USAF air-to-ground, air-to-air, and radar bomb scoring sites and ranges.

An incremental approach should be employed, making maximum use of existing systems and equipment, and so scheduled as to maintain continuity of range operations as the continuous improvement proceeds.

### 3.2 GENERAL DESCRIPTION

Although specific required characteristics and capabilities will vary with the function, location, and size of each range, the primary developmental goals common to most ranges/sites include the following:

a. Low-cost operation.

b. Maximum combat realism.

c. Rapid and accurate data reduction and reporting.

d. Maximum range flexibility and equipment mobility so that range instrumentation can be moved to different terrestial, climatic, or operational locations.

e. Minimum impact on operational equipment (modification, etc.).

f. A capability to integrate more than one range into a network to facilitate evaluation of large strike-size test and training missions.

To some degree these goals are contradictory and their interaction will bring about the final configuration at each range. Funding, geographic and environmental constraints apply to each of the goals.

In any event, an overriding goal is the provision of a test environment in terms of equipment, people, and procedures which will make the tests highly credible to the users and build confidence in the test results. Some of the factors contributing to these desired ends are given in the Figure 3-1.

## 3.3 TT&E SEGMENTS

TT&E improvements must be implemented in discrete, functionally-interconnected segments. While some ranges may receive improvements in each segment, most improvements on a given range will address only selected segments. The six segments are illustrated in Figure 3-2 and a description of each of the segments follows:

### 3.3.1 Simulated Enemy Threat

The threat segment consists of equipment designed to simulate enemy force dispositions: SAM/AAA, early warning and acquisition radars, ECM and IFF systems, and command, control and communication systems.

### 3.3.2 Targets

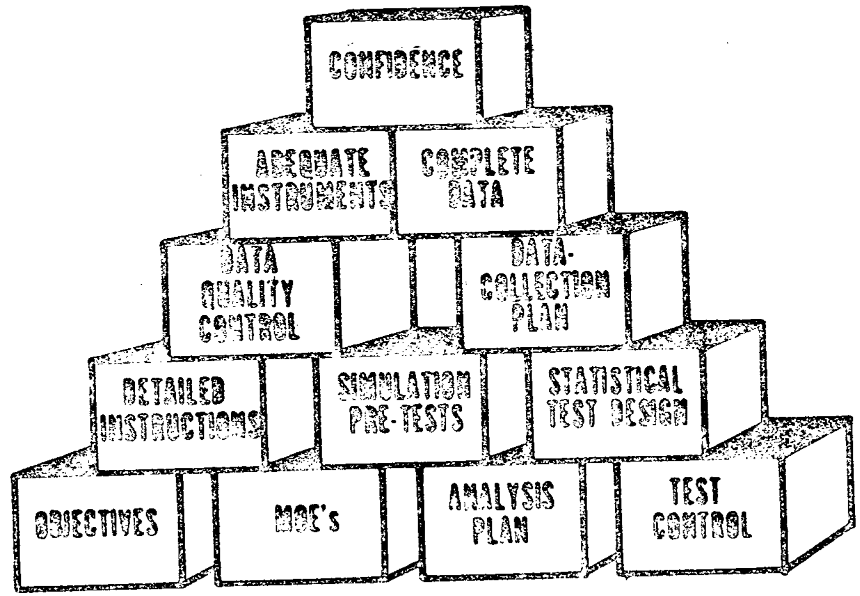
This segment consists of ground fixed, ground mobile, and airborne targets representative of enemy equipment. Integration of targets with scoring systems is an objective for this segment.

### 3.3.3 Instrumentation

This segment includes much of the electronic data acquisition equipment such as:

a. Time-Space-Position Information (TSPI). Effort in this area should include emphasis on development/acquisition of systems for range/mission control, safety and scoring. It includes conventional radar, optics, and laser systems. It also includes multilateration systems such as ACMI and RMS/SCORE.

# HOW CAN WE BUILD CONFIDENCE IN TEST RESULTS?




- CLEARLY STATED TEST OBJECTIVES
- WELL CHOSEN, PERTINENT MOE's
- EXPLICIT, DETAILED ANALYSIS PLAN
- STATISTICAL TEST DESIGN WITH...
  - ADEQUATE SAMPLE SIZES
  - USE OF SIMULATION & PRE-TESTS
- FIRM CONTROL OR KNOWLEDGE OF TEST CONDITIONS
- DETAILED & STANDARDIZED INSTRUCTIONS TO PARTICIPANTS
- EXPLICIT & COMPLETE DATA-COLLECTION/PROCESSING PLAN
- COMPLETENESS & REDUNDANCY OF MEASUREMENTS
- UNCOMPROMISING DATA QUALITY-ASSURANCE PROCEDURES
- INSTRUMENTATION ACCURACY ADEQUATE FOR OBJECTIVES

Figure 3-1

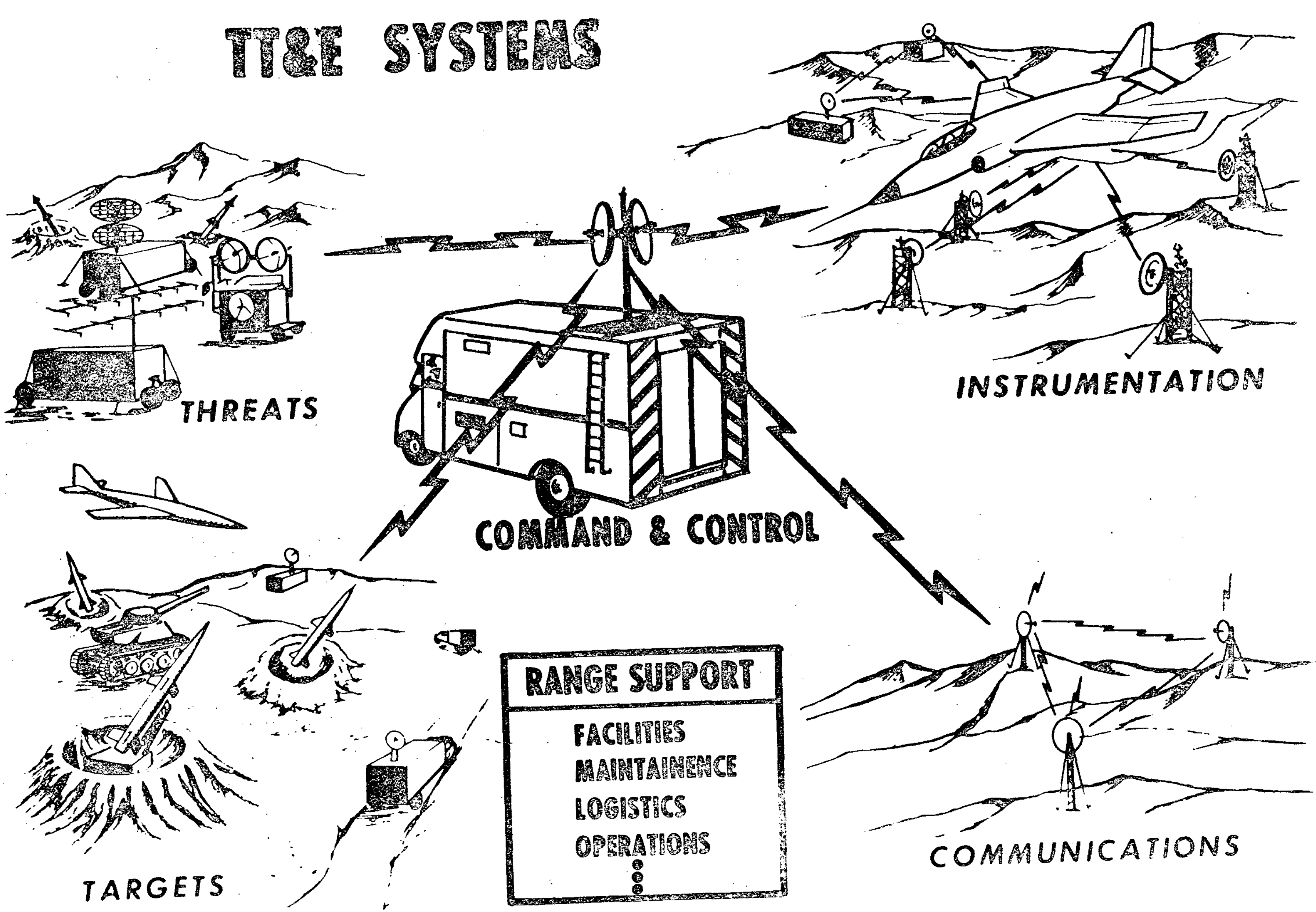

TT&E SYSTEMS
THREATS
INSTRUMENTATION
COMMAND & CONTROL
TARGETS
COMMUNICATIONS
RANGE SUPPORT
FACILITIES
MAINTAINENCE
LOGISTICS
OPERATIONS

Figure 3-2

(1) Air Combat Maneuvering Instrumentation (ACMI). This instrumentation provides a capability for tracking and display of all participants in an air-to-air engagement, with sufficient accuracy and data rate to allow evaluation of the maneuvers performed, and scoring of the engagement.

(2) RMS-II/SCORE. Provides essentially the same capability as ACMI above.

(3) Conventional Radar, Optics, Lasers. TSPI instrumentation to provide data for control, safety, and scoring.

b. Scoring. Instrumentation is required for live and simulated scoring of missiles, rockets, guns, bombs, and electronic warfare.

(1) Simulated Scoring. This includes equipment and techniques for scoring of simulated releases and launches of munitions.

(2) Actual Scoring. For those ranges where actual munitions (Bomb/Rocket/Strafe) or training munitions can be expended, the goal is to provide suitable scoring systems for delivery evaluation and impact determination.

(3) Electronic Warfare (EW) Scoring. This includes a family of equipment and techniques used to evaluate the effectiveness of electronic warfare.

### 3.3.4 Command and Control

This segment involves such functions as general air traffic surveillance, mission scheduling, range safety, radio frequency monitoring and management, and similar matters.

### 3.3.5 Communications

This segment involves the radio, wire, and other means for transmission of range command/control, data, and miscellaneous other communications from point to point on the range including the vehicles used in the OT&E missions.

3.3.6 Range Support Equipment

This segment includes such items as data processing and recording equipment, displays, standard pods, primary power supply, range peculiar support equipment, and support facilities.

## 3.4 CURRENT RANGE CAPABILITIES AND IMPROVEMENT PLAN

As the TT&E Improvement Program progresses, separate schedules for each RBS site and range selected for improvement based on requirements identified should be added as appropriate. Each schedule should summarize the mission of the range, present a description of current capability, list current range equipment, and give the range improvement plan for each applicable segment. A listing of OTT&E Ranges to which such an improvement effort could be applied is:

a. Air Force Land Ranges

Avon Park FL
Badlands SD
Blair Lake AK
Clairborne LA
Cuddeback Lake CA
Dade County NC
Edwards AFB CA
Eglin AFB FL
Luke AFB AZ
Matagorda TX
Melrose NM
Nellis NV
Pointsett SC
Saylor Creek ID
Smoky Hill KS
Wendover-Hill Complex UT

b. Overwater Ranges

Eastern Test FL
Gulf Test FL
Gulfport MS
Lake Superior MN
Matagorda TX
Myrtle Beach SC
Nantucket Shoals MA
Oswego NY
Savannah GA
Syeboygan WI
Upper Lake Huron MI
Western Test CA

c. Air Force Reserve/Air National Guard Land Ranges

Camp Atterbury IN
Camp Grayling MI
Camp Shelby MS
Fort Carson CO
Fort Drum NY
Fort Chaffee AR
Fort Sill OK
McMullen TX
Smoky Hill KS
Volk Field WI
Warren Grove NJ

d. Army Ranges Used by USAF

Dugway UT
Ft Huachuca AZ
Leach Lake CA
Oscura/Yonder NM
Peason Ridge LA
Red Ridge NM

e. USAFE Ranges

Bardenas-Reales, Spain
Baumholder, Germany
Cowden, Great Britain
Dutch, Off Coast of Netherlands
Helchtern, Belgium
Holbeach, Great Britain
Ibizia, Off Coast of Spain
Incirlik, Off Coast of Turkey
Jurby, Off Coast of Great Britain
Konya, Turkey
Maniago, Italy
Otterburn, Great Britain
Siegenburg, Germany
Suippes, France
Vliehor, Netherlands
Tain, Scotland
Tymbakion, Crete
Wainfleet, Great Britain

f. PACAF Ranges

Chandy (Thai operated), Thailand
Crow Valley, Philippines
F.S. (Chinese operated), Taiwan
Idensuna Jima Island, Okinawa
IE Shima, Okinawa
KoonNI, Korea
Nightmare (ROK controlled), Korea
Shui Chi (Chinese operated), Taiwan
Tabones/LosFrailes (USN controlled), Philippines
Tiro Shima, Okinawa
Udorn (Thai controlled), Thailand

g. Fixed RBS Sites

| | |
|---|---|
| Anderson AFB, Guam | Matagorda TX |
| Asland ME | NKP, Thailand |
| Bismarck ND | Ramstein, Germany |
| Fort Drum NY | Richmond KY |
| Hastings NB | Statesboro GA |
| Hawthorne NV | Ubon, Thailand |
| Holbrook AZ | Udorn, Thailand |
| La Junta CO | Wilder ID |

Figures 3-3 and 3-4 show the range locations.

## 3.5 RED, WHITE AND BLUE FORCE CONCEPT

### 3.5.1 Blue Force

The aircraft weapons or other elements engaged in attack, penetration, or otherwise interacting with the range enemy are considered the Blue Force. Blue Force or range user elements are usually provided by the range user who in most cases is a force temporarily deployed to a range for test and/or training.

The Blue Force consists of USAF units from any of the operational commands conducting training, test, or exercise missions on a given range/RBS site. The types of Blue Force aircraft and equipments to be accommodated are listed in Table 3.1.

The types of mission support required for the Blue Forces are:

- Augmentation of Blue Command, Control, and Communications ($C^3$), when required.

- Augmentation of Blue Force ground-based operational equipment or provision of sites for this equipment.

- Logistic support of Blue Force elements, when required.

### 3.5.2 Red Force

Any portion of a range that replicates a hostile or enemy capability either functionally or by physical simulation is considered part of the Red Force. This includes the threat and target segments and any ground

# CONTINENTAL NEEDS

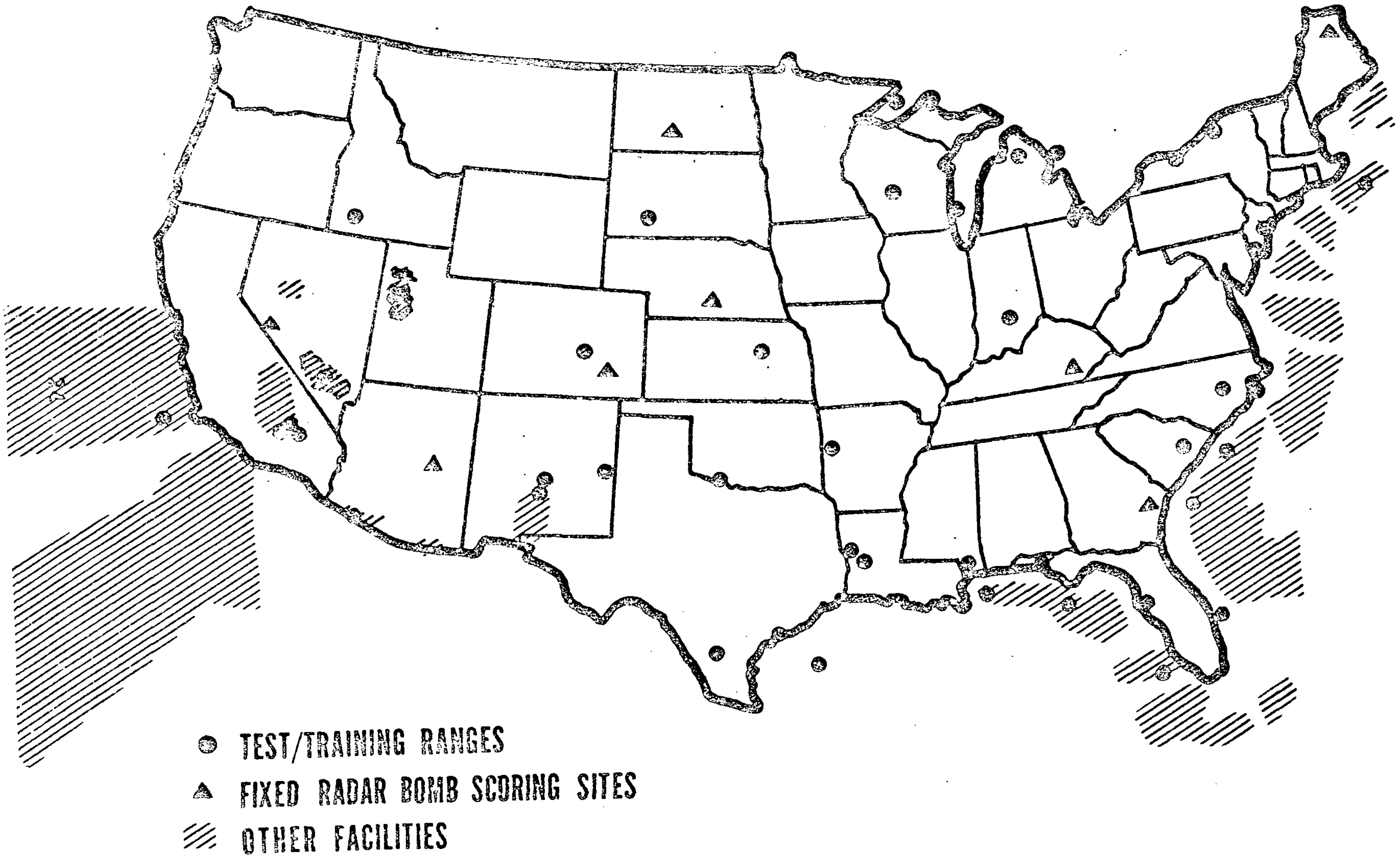
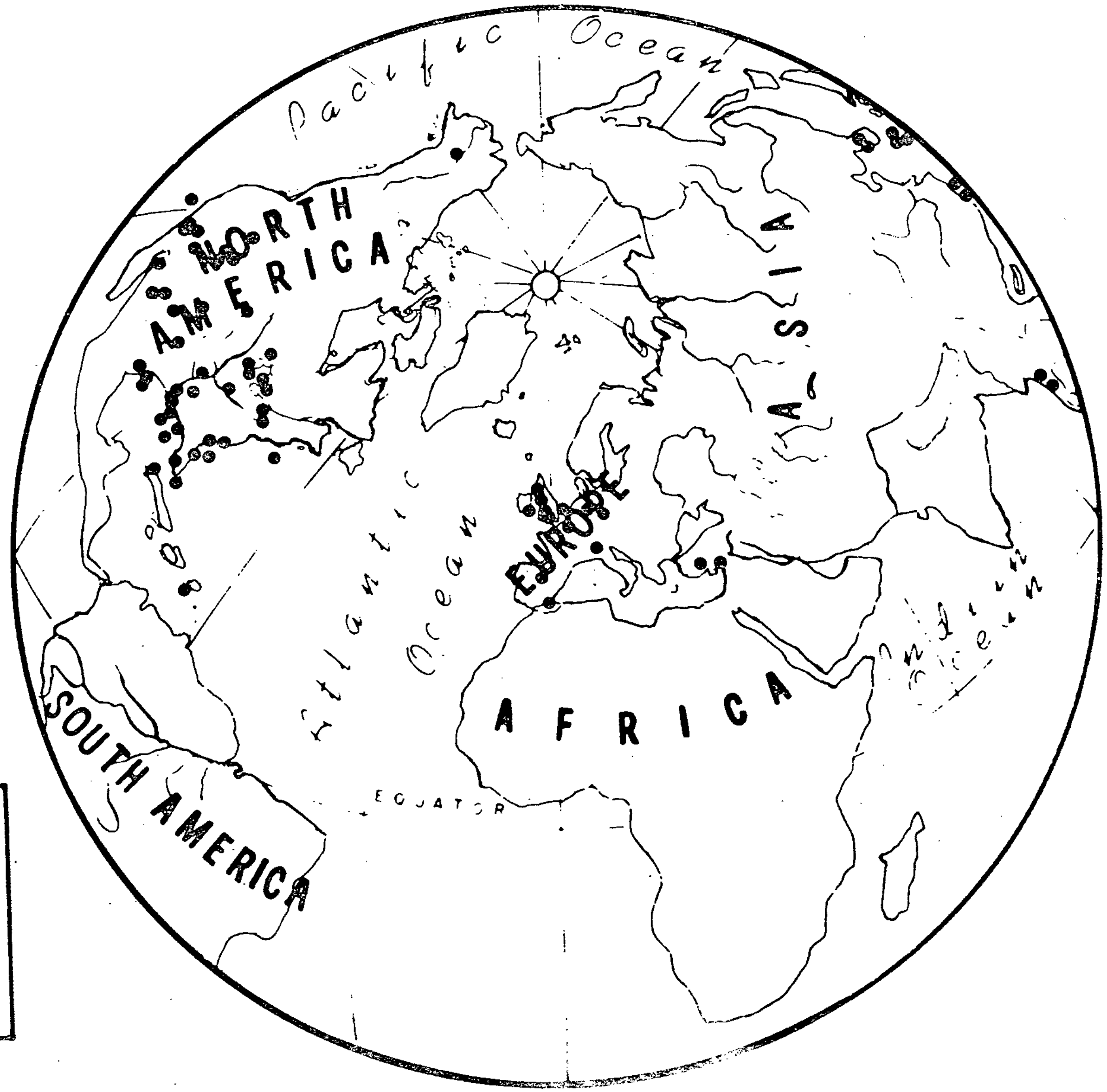



Figure 3-3

# NEEDS




| NO. RANGES | LOCATED IN |
|---|---|
| 47 CONUS | 29 STATES |
| 18 USAFE | 8 COUNTRIES |
| 15 PACAF | 6 COUNTRIES |
| 1 AAC | 1 STATE |
| 1 USAFSO | 1 TERRITORY |

Figure 3-4

## TABLE 3.1

## BLUE FORCES

TYPES OF AIRCRAFT, WEAPONS AND EW DEVICES TO BE ACCOMMODATED

| Aircraft | EW Devices | Weapons |
|---|---|---|
| F-4 | Jammers | Guns |
| F-5 | ALQ-71 | AIM-4 |
| F-105 | ALQ-72 | AIM-7 |
| F-111 | ALQ-87 | AIM-9 |
| F-15 | ALQ-94 | AIM-54 |
| F-16 | ALQ-101 | |
| A-6 | ALQ-105 | AGM-12 |
| A-7 | ALQ-117 | AGM-45 |
| A-10 | ALQ-119 | AGM-65 |
| A-37 | ALQ-131 | AGM-69 |
| RF-4 | ALQ-135 | AGM-78 |
| O-2 | Chaff or Flare | AIR-Z |
| OV-10 | ALE-2 | Gravity Bombs |
| E-3A | ALE-20 | Guided Bombs |
| C-130 | ALE-24 | Rockets |
| C-141 | ALE-28 | Mines |
| | | Cluster Bombs |
| KC-135 | ALE-29 | |
| B-52 | ALE-38 | |
| B-1 | | |
| RPVs | Receivers | |
| CH-53 | | |
| | ALR-20 | |
| F-106 | ALR-31 | |
| F-102 | ALR-41 | |
| FB-111 | ALR-48 | |
| SR-71 | ALR-53 | |
| E-4 | ALR-56 | |
| C-7 | RHAW | |
| | APR-35/36 | |
| | APS-109 | |
| | Expendable jammers | |
| | Decoys | |

or air elements that have been assigned a hostile role for a particular test or exercise. The Red Force is generally the responsibility of the range owner/operator.

#### 3.5.3 White Force

That part of a particular range's function/equipment dedicated to evaluation of Red/Blue engagement is the White Force. This includes such items as the instrumentation, TSPI, scoring, EW evaluation, and range support segments such as command, control and safety.

#### 3.5.4 Relationships

Figure 3-5 illustrates some of the relationships of Red, White and Blue Forces in the EW scoring aspect of observations.

### 3.6 RANGE SAFETY

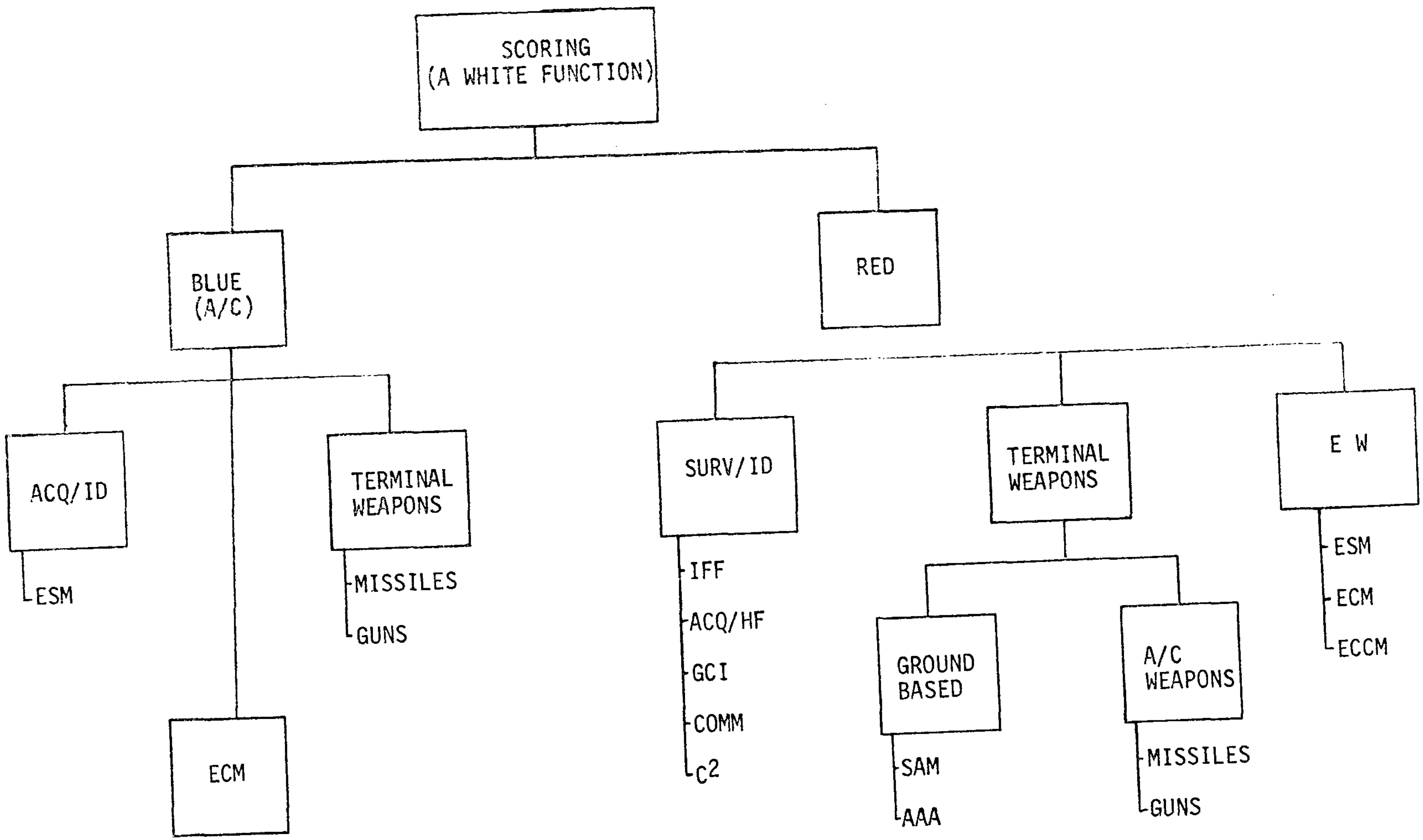
The commander of each range is responsible for assuring maximum safety (air and ground) consistent with operational requirements for all systems including aircraft, missiles and unmanned airborne vehicles operating on each range facility. He is also responsible for all such vehicles requiring overland flight testing, training, or evaluation which cannot be contained within existing range boundaries and are launched either from within range boundaries or for flight activity into the range. (Includes cognizance for influences upon the natural environment and non-participating systems.)

#### 3.6.1 Safety Constraints

Specific improvements for each range should be designed to provide the capability for the safe conduct of testing and training to the following degree.

a. The probability of damage or injury to non-participating system or personnel should not exceed $5 \times 10^{-6}$.

b. Participating systems or personnel should be subjected to no greater probability of damage or injury than $5 \times 10^{-5}$ per missions. This criterion should




EW SCORING CONSIDERATIONS

FIGURE 3-5

be satisfied through the design of the range equipment, primarily with hardware/software characteristics, and secondarily with operating procedures. Analyses and trade studies should substantiate a practical combination of hardware/software/procedures to achieve practical levels of safety.

On the basis of the above criteria, methods and materials for the continued use of range safety personnel must be provided. These are to be used for application in the analysis and assessment of individial missions/projects to permit day-to-day trade-offs as to the nature and philosophy of range control and operation.

### 3.6.2 Safety Considerations

Figure 3-6 was developed by Starr, a recognized authority on risk analysis. This figure portrays both the benefits and the risks (probability of fatality, $P_f$) one is willing to take in a sampling of categories. Starr theorizes that if one doubles the benefit, a person is willing to take eight times the risk. As shown on Figure 3-6, there is a level at which the risk (probability of fatality) is too great for voluntary participation. Beyond that threshold, the participation is on an involuntary basis. The risk associated with the role of an experimental test pilot is great but the benefits (monetary, prestige, personal desires, and others) provide sufficient compensation that he performs voluntarily.

How do we cope with the forces that bear on the safety problem? First, determine what hazards exist then by analysis, understand the cause of the hazard, and finally treat or take actions to influence the cause. We must accept the concept of risk and by our own actions create for ourselves acceptable levels of risk. By doing this we can design acceptable systems that are safe at minimum costs. Safety aspects can be dealt with and controlled by responsible actions instead of controlling system design and/or performance.

### 3.6.3 Cost of Safety

Present safety statistics are based upon accidents per thousand hour of flight time. While completely valid from an operational viewpoint, such a statistical

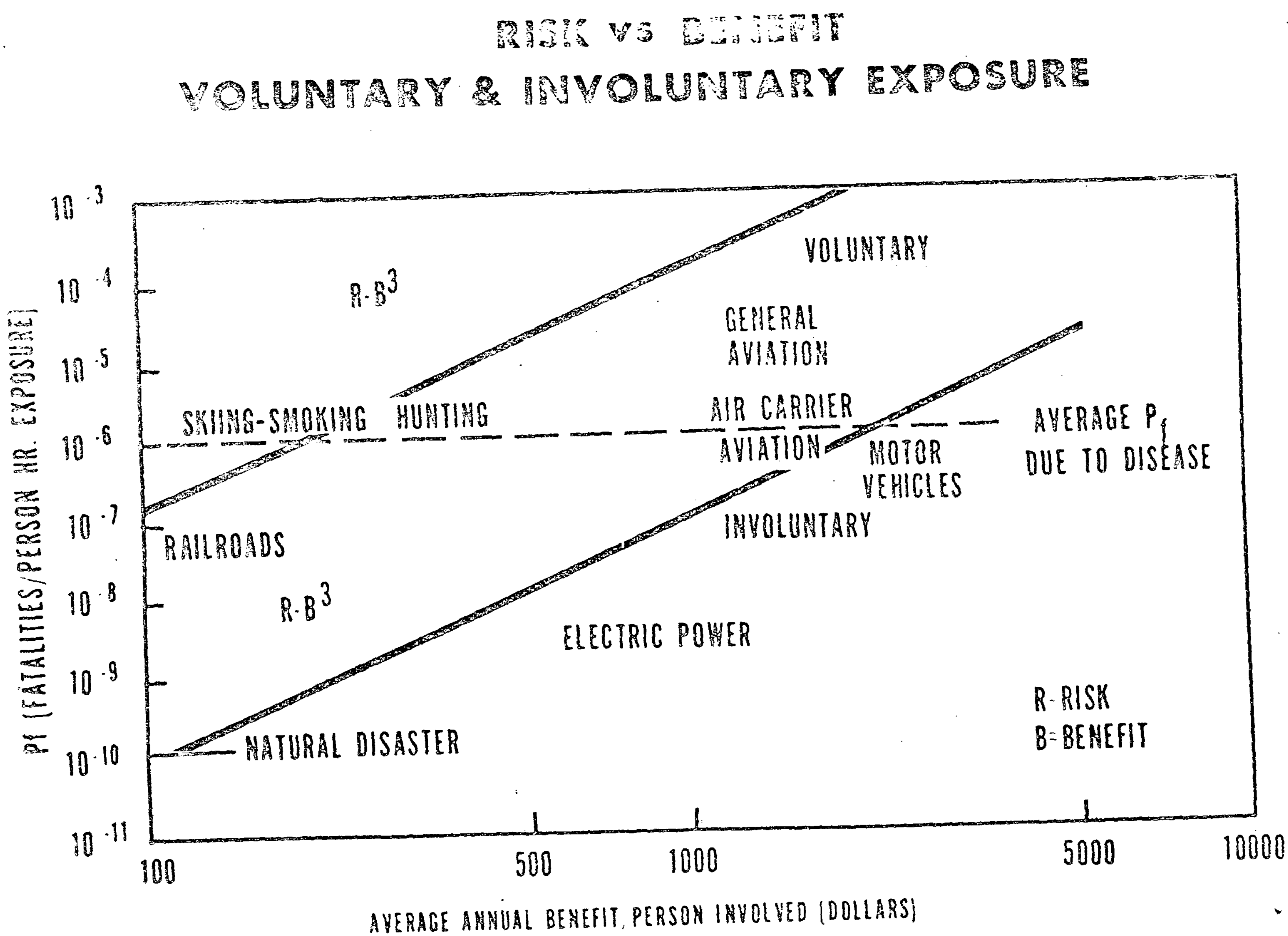

RISK vs BENEFIT
VOLUNTARY & INVOLUNTARY EXPOSURE
VOLUNTARY
R-B3
GENERAL AVIATION
SKIING-SMOKING
HUNTING
AIR CARRIER AVIATION
AVERAGE Pf DUE TO DISEASE
MOTOR VEHICLES
RAILROADS
INVOLUNTARY
R-B3
ELECTRIC POWER
NATURAL DISASTER
R-RISK
B=BENEFIT
Pf (FATALITIES/PERSON HR. EXPOSURE)
10-3
10-4
10-5
10-6
10-7
10-8
10-9
10-10
10-11
100
500
1000
5000
10000
AVERAGE ANNUAL BENEFIT, PERSON INVOLVED (DOLLARS)

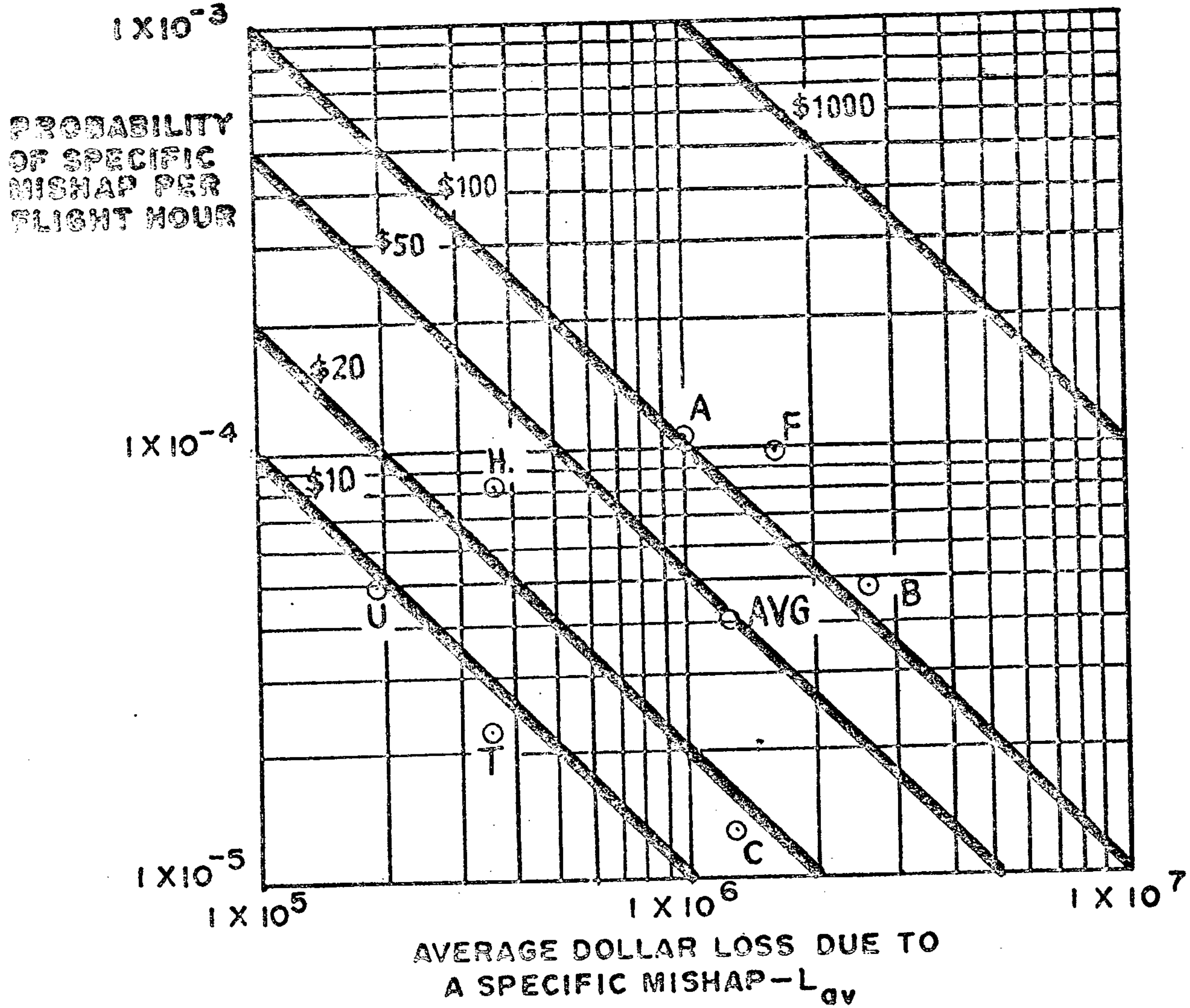
FIGURE 3-6

approach does not present a cost basis to determine the dollar worth of safety improvements. Figure 3-7 shows the average dollar loss of aircraft by type per flight hour and illustrates that the predominate range users - (a) Attack, (f) Fighter, (B) Bomber are the high loss leaders. Range improvements which reduce the probability of mishap can therefore significantly reduce the AF dollar expenditure. Safety improvements should be considered on an equivalent basis with reliability and maintainability in life cycle costing, integrated logistics, and design to cost guidelines. To implement this concept, revisions are in work to AFR 127-8, AFR 800-8, AFR 800-11, AFP 800-7 and DH 1-6 Design Handbook.

### 3.6.4 Safety Directives, Regulations/Guidelines

Figure 3-8 outlines the pertinent current directives governing safety. It portrays the directives for both the operator and the developer. Although these directives attempt to cover all aspects of safety, situations will arise where innovative and creative thinking are needed to resolve problems not directly addressed. Both the developer and operator must be ever alert to safety problems and take prompt actions to define and eliminate the cause.

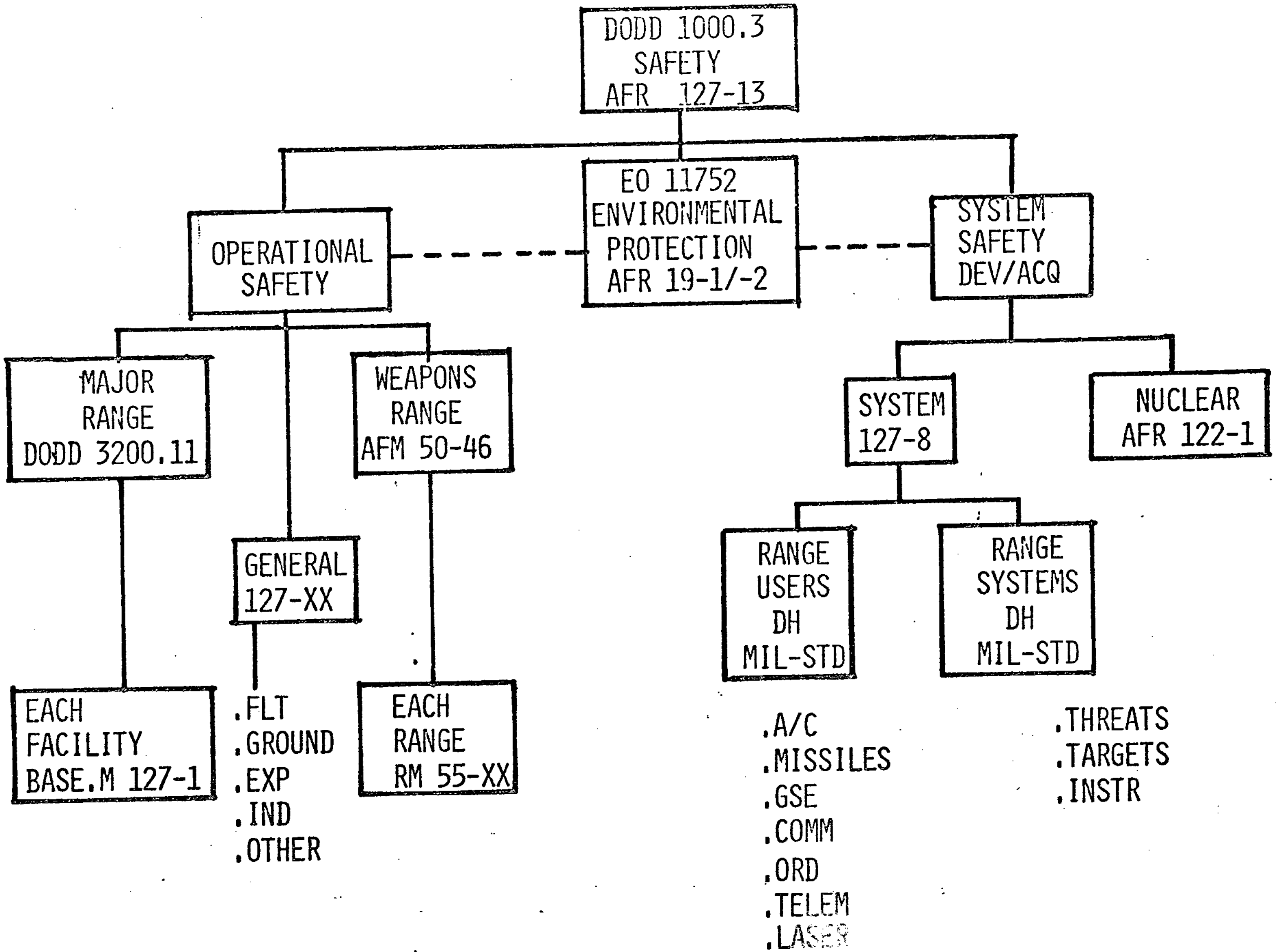
MAPPING OF DOLLAR LOSS TO THE AIR FORCE PER FLIGHT HOUR, 1969-73 FOR MAJOR/MINOR AIRCRAFT ACCIDENTS




A-ATTACK
B-BOMBER
C-CARGO
F-FIGHTER
H-HELICOPTER
T-TRAINER
U-UTILITY

NOTE: INCLUDES ONLY AIRFRAME LOSSES

Figure 3-7




CURRENT DIRECTIVES GOVERNING SAFETY

Figure 3-8

# SECTION 4

# TECHNICAL CONSIDERATIONS

## 4.1 INTRODUCTION

The TT&E Improvement Program involves a large number of ranges, RBS sites, and other training areas, each with unique characteristics. It is not the intent here to provide generalized solutions to all TT&E improvement problems. Rather, the purpose of this section is two fold: first, to emphasize the process by which TT&E improvement may best be accomplished, and second, to illuminate the technical aspects of TT&E improvements that must be considered.

## 4.2 REQUIREMENTS DEFINITION

The process of improving OTT&E must be based on an in-depth realistic evaluation of the specific requirements in each of the OTT&E segments: Threats, Instrumentation, Communications, Command/Control, Targets, and Range Support Equipment. The basic definition of the requirement (Required Operational Capability/ROC) should mandatorily address the OTT&E requirements. If this is done in the early stages, adequate test and training plans can be made to maximize the benefits to both the developer and user. Defining these requirements for a range/site on which OTT&E of weapon systems and crews can be performed involves the following steps:

a. Assimilation of Air Force OTT&E and training requirements documented in ROCs (Required Operating Capability Statements), studies like HAVE EDGE and the USAF CONUS Range Study, transcripts of testimonies at Congressional hearings by DDR&E officials and Air Staff, intelligence information and guidance documents for OTT&E improvements.

b. Periodic surveys conducted by writing to all Air Force Commands for "Quick-Look" updates of their potential test and training requirements.

c. Field visits to contact all potential range users as well as appropriate members of the intelligence and development community.

On the premise that TT&E of a weapon system is done in the context of the missions for which the weapon system was designed, representative mission scenarios have been developed from the information obtained in the above steps (a-c) for current requirements. (See 2FTP - H0386002.) These scenarios describe how the potential range users conduct their missions, the objectives of their test and training programs, their analysis plans, and their criteria for assessment of performance. The scenarios were analyzed to identify measurements of performance and the variables which affect performance. These data should allow the users to assess performance by the operational crews using the weapon system over all facets of the missions under various conditions of interest. Estimates were also made of the precision with which the measurements should be made based on the identification of the information that the user desires as derived from the mission analysis. A range concept was developed to demonstrate what range functions had to be performed to meet test or training objectives.

The range functions identified for all the representative scenarios have been brought together to show the total of the TT&E segments, range safety, and air/land space requirements. These identified requirements were compared to the current capabilities of the ranges available to each command. Summaries of the requirements needed to provide the improved TT&E capability were developed by range for each Command. The requirements desired for each range form a firm basis for the development and acquisition necessary to support Air Force TT&E improvements and are documented in related document 2FTP - HO386002.

4.2.1 Requirements Processing

The Secret document 2FTP - H0386002, "Requirements Analysis for Improvement of USAF OTT&E," represents an in-depth survey of the requirements for USAF ZI test and training ranges. This document (2FTP - H0386003) and one other document, 2FTP-HO386004, "Intelligence Considerations for Improvement of USAF OTT&E," Secret, provide

supporting technical and intelligence information for the capability requirements stated in 2FTP - HO386002. It is recommended that headquarters USAF validate the capabilities contained in these documents as a class of requirements necessary to improve USAF testing and training. After validation, it is proposed that quantities from this family be authorized and provided anually to overcome the existing OTT&E deficiencies and improve operational capabilities.

This could be accomplished incrementally as the budget will allow. The validation of these documents will simplify and expedite the normal justification process associated with the Required Operational Capability (ROC) preparation in accordance with AFR 57-1.

### 4.3 TT&E SYSTEM SEGMENTS

In earlier sections the TT&E system was subdivided into six segments or subsystems which were briefly described in section 3.3. The succeeding six subsections deal in detail with the equipment and related matters for each segment as follows:

| Segment | Subsection |
|---|---|
| Threats | 4.4 |
| Targets | 4.5 |
| Instrumentation | 4.6 |
| Command and Control | 4.7 |
| Communications | 4.8 |
| Range Support | 4.9 |

### 4.4 SIMULATED ENEMY THREATS

A large number of test and training threat radar simulations exist within Air Force and Navy resources. (See Figure 4-1.) The Air Force simulators available in AFSC are used for DT&E, support of IOT&E, OT&E, and large scale training exercise. Current SAC and TAC capability is largely for aircrew training, however, OT&E capability is planned. The Navy systems support essentially the same kind of programs but also support testing of anti-radiation missile developments.

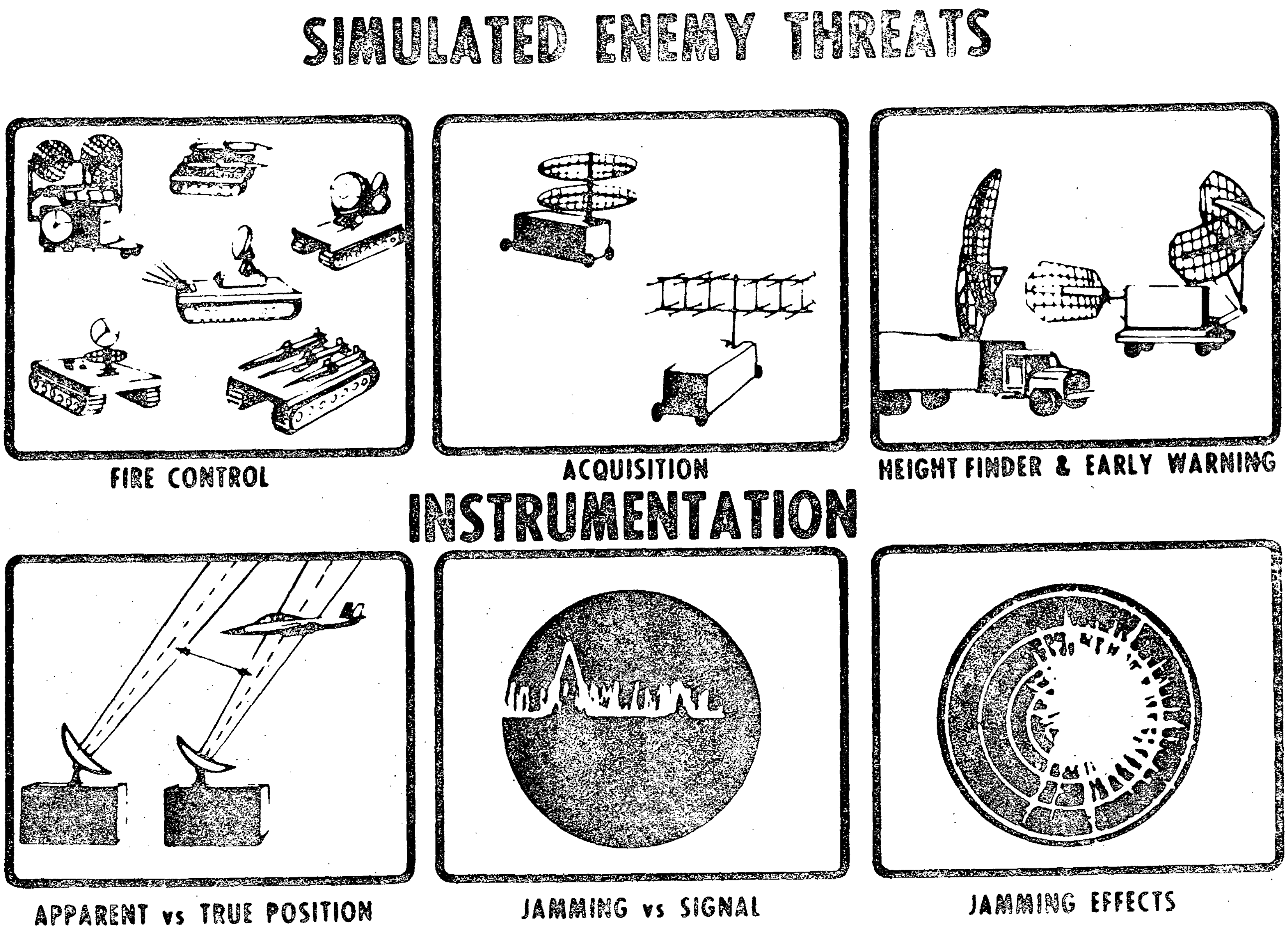

SIMULATED ENEMY THREATS
FIRE CONTROL
ACQUISITION
HEIGHT FINDER & EARLY WARNING
INSTRUMENTATION
APPARENT vs TRUE POSITION
JAMMING vs SIGNAL
JAMMING EFFECTS

Figure 4-1

A broad scale survey of Electronic Warfare Threat Simulations has been made by TESPO and is published as a companion Secret document, "Survey and Information for Selection of Threat Simulators for USAF Operational Training, Testing and Evaluation (OTT&E)", 2FTP - HO386007.

This volume includes all information available from the Threat Simulator Survey on both hardware and computer simulation systems and facilities, their use, location, how they work together, plans for improving existing simulators and procurement of new ones: intelligence inputs on Soviet systems including risk assessment in developing new simulators and a prioritized list of threat simulations recommended for development.

The volume covers the following aspects of threat simulator use:

Testing
Training
Exercise
Planning
Development
Funding

Threat simulations can be grouped as follows:

a. Emitters.

b. *"Full-up" radars with operators.

c. "Full-up" radars with operators and including a scoring capability.

Emitters are the simplest form of Radar Simulation. They are designed to radiate an RF signal that duplicates a particular threat radar signal (e.g., SA-2, SA-3). The emission of the appropriate signal is accomplished through

*"Full-up" radars refer to threat simulations in which the "threat" is a full functional replication of an actual enemy threat including radar, operators and procedures.

various modulation, frequency shift and antenna techniques. Emitters are used primarily to activate Radar Homing and Warning (RHAW) devices on various types of aircraft and alert the aircrew that their aircraft is being illuminated by a threat. Emitters can be built to generate either omni-directional or directional signals or, if desired, the antenna may be slaved to an IFF Tracker so that the antenna is always tracking a particular aircraft. When used in this manner, emitters are often coupled with a remote antenna for anti-radiation missile (ARM) testing. An example of this type of threat simulation is located at the Nellis AF Base Caliente Range and is being used extensively for Wild Weasel Training. In the case of ARM Testing, the emitters are located at the Naval Weapons Center, China Lake, California, for launch testing of the passive/ homing guided weapon.

The full-up radars are complete replications of a particular enemy threat radar system. They include all of the subsystems of the threat system (i.e., transmitters, receivers, antennas, display scopes, etc.) and require operators to perform all of the functions as performed in the actual threat systems. In most instances, the system is designed to have the exterior physical as well as electronic appearance of the actual threat system. This type of system is much more sophisticated and costly than the emitter only system. They are used in training programs and OT&E in which the effects of ECM must be evaluated. Examples of these systems are the QRC-207 SA-2 Simulator and West II Early Warning Radar Simulator at Eglin AF Base; the MPQ-T7 and MPQ-T8 Simulators at Nellis AF Base.

The third group are also full-up radars but include a capability to score the effects of ECM. In this design, a computer and a computer model of a specific SAM missile are added. Scoring the effect of ECM on the radar is stated in terms of miss-distance which can be determined in various ways, one of which is briefly described. In the case of the Air Force MPS-T1 which can simulate any of three different SAM radars, one of the pedestals which is not programmed to be jammed will provide a reference track of a beacon on the target aircraft while operators controlling one of the other two pedestals affected by

ECM is attempting to track the apparent position of the target aircraft. Both the reference track position and the apparent position from the radar being jammed are passed on to the computer. When the missile launch button is depressed, the computer works out the missile flight profile to the target position as determined from the system being jammed. At the end of missile flight time to the target position, the computer determines the difference between the reference target position and the actual target position indicated by the radar being jammed and a print-out showing missile miss-distance in feet is made. These systems are employed by both TAC and SAC and have been used for both training and OT&E.

To be useful for OT&E and training, the threat simulators must adequately duplicate the aspects of the enemy system being simulated, whether it be emissions only or a full-up radar. The process (see Figure 4-2) of assuring the adequacy of the simulation is referred to as validation. For the Air Force the validation process is the responsibility of the Foreign Technology Division of the Air Force Systems Command. The validation process may be summarized as:

a. The compilation of the intelligence data input package (IDIP) from FTD for use by the developer in specifying characteristics of the model or simulator design, or alternatively as valid input parameters from established simulators.

b. Specification of validation tests, monitoring these tests and evaluation of test results for comparison of simulator performance with real and/or estimated threat performance.

c. Certification that the simulator has been compared with current knowledge of the enemy system and does represent the foreign system. Deficiencies, if any, will be identified.

## 4.5 TARGETS

Proper conduct of OTT&E missions requires both airborne and ground targets (See Figure 4-3). Ground targets are further categorized as stationary or mobile.

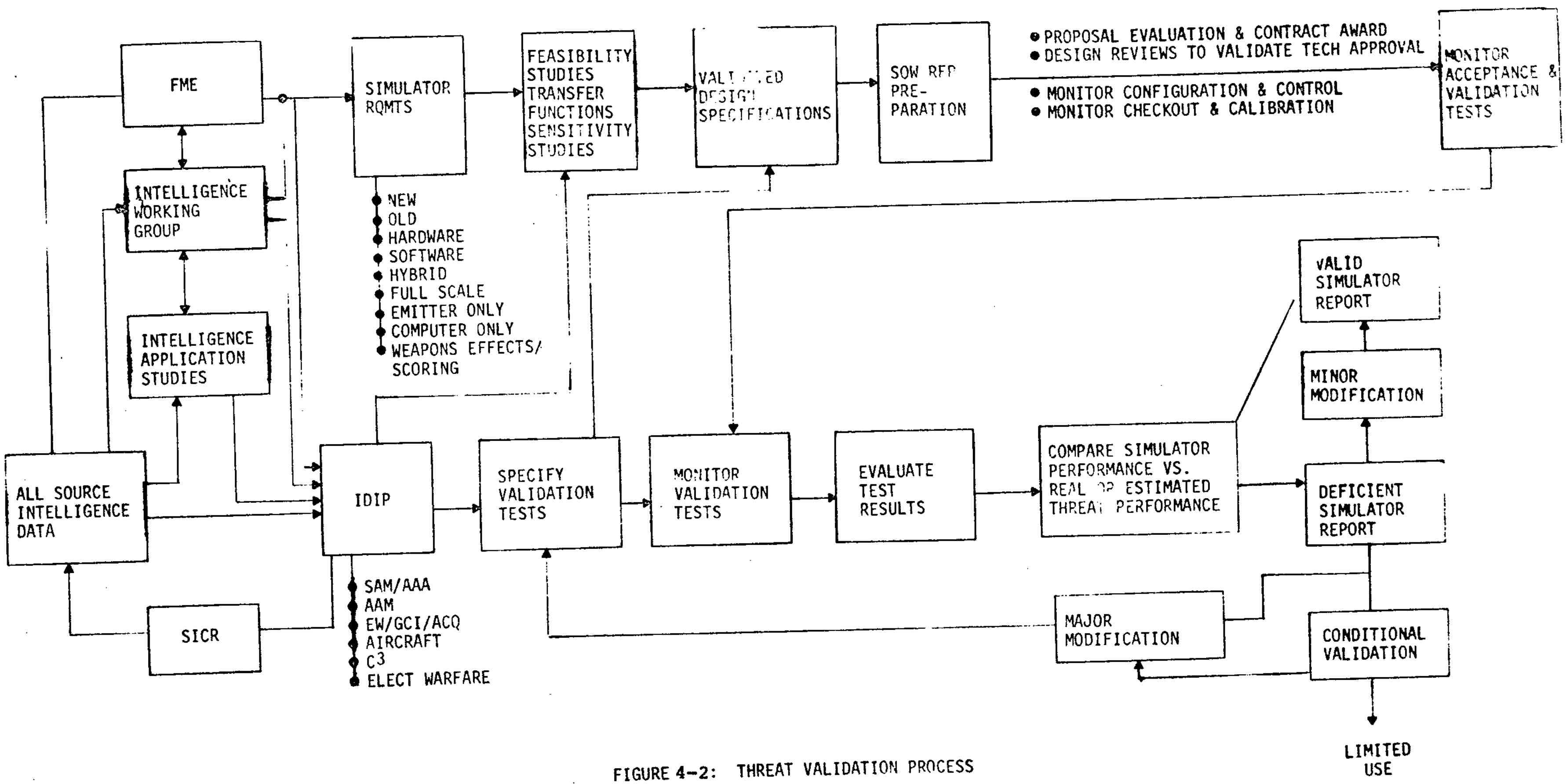



FIGURE 4-2: THREAT VALIDATION PROCESS

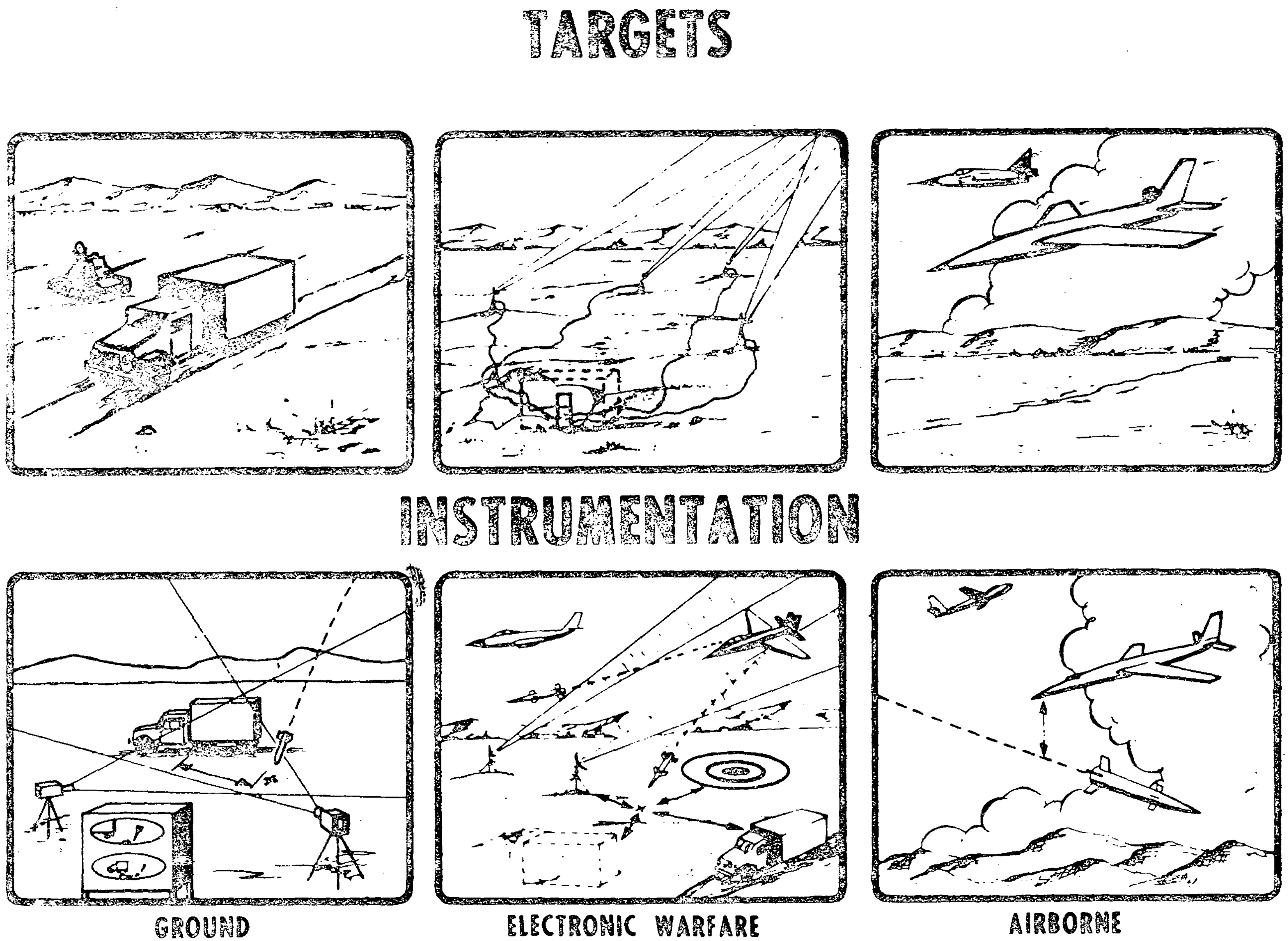

TARGETS
INSTRUMENTATION
GROUND
ELECTRONIC WARFARE
AIRBORNE

Figure 4-3

Whether the targets are ground or airborne, they must possess realistic characteristics to provide meaningful test and/or training. A survey of ground targets has recently been conducted by AFSWC/TESPO and is published as a related document "Survey and Information for Selection of Ground Targets for USAF OTT&E", 2FTP - HO386006. DDR&E is conducting a detailed survey of airborne targets requirements and capabilities through a contract to the Mitre Corporation.

### 4.5.1 Ground Targets

As mentioned above, ground targets consists of two categories; stationary and mobile. In the stationary category, there are fixed electronic warfare emitters and fixed site targets such as rail, bridges, ammunition dump replicas, and airfields.

#### 4.5.1.1 Fixed EW Emitters

These consist of hardened modulated emitters which simulate real threat emission and which are associated with above ground, expendable mock-ups of air defense radar sites against which live ordnance may be expended for ARM training. Provisions should be made for remote control of RF emissions to permit simulation of Red Force emission control tactics used during defense suppression type operations. It is very important that the RF emissions be valid for the actual target being simulated.

#### 4.5.1.2 Fixed Sites

The other fixed targets consist of simulated enemy resources (passive) such as fuel and ammunition dumps, bridges, railways, airstrips, troop concentrations or camp areas, and other terrain features similar to the areas beyond the FEBA. These targets generally require routine civil engineer or contract services for initial buildup and repair or replacement as required. More realism sometimes can be obtained by the use of camouflage.

### 4.5.2 Airborne Targets

Several versions of airborne targets are available. Some are towed (Towbee, Dart, FIGAT) and some are self-powered (BQM-34A/F, PQM-102, HAST). The DDR&E study now

underway through the Mitre Corporation will better define the airborne target requirements and availability. Figure 4-4 shows some of the types of enemy aircraft that might possibly be encountered. The physical and performance characteristics of each to be simulated should be well defined so realistic airborne targets can be produced for valid testing and training.

## 4.6 INSTRUMENTATION

The subsections which follow discuss data acquisition systems which, in some cases, include rather extensive display and computing facilities as part of the subsystem identified. The discussion of specific systems is preceded by a general discussion of evaluation equipment and methodology.

### 4.6.1 Electronic Warfare Evaluation Equipment and Methodology (Figures 4-5 and 4-6)

As a penetration aid to an aircraft strike force, the objective of electronic warfare is to enhance the probability of a strike force penetrating an air defense system to the point of ordnance delivery and exiting safely. The effectiveness of electronic warfare can be related directly to its ability to prevent, delay or degrade the occurrence of critical functions of the air defense system. Since a major portion of a training range activity can involve EW effectiveness evaluation, the instrumentation must be comprehensive enough to allow evaluation of all aspects of EW; e.g., communications jamming, attrition of defense elements (as enhanced by EW), electro-optical and IR countermeasures, attrition of strike aircraft, air defense use of ECM/ strike force use of ECCM, utilization of Elint and SIGNT, etc.

#### 4.6.1.1 Measures of Effectiveness

Measures of effectiveness for EW can be associated with the various events which occur when a strike force is engaged by an air defense. The ultimate measure of effectiveness is the kill probability of strike aircraft by the air defense, or the aircraft attrition in meeting the strike objectives. Evaluating this involves measuring the miss-distance of the simulated

| AERIAL TARGETS STUDY | AIRCRAFT-THREAT SYSTEMS |
|---|---|

| FIGHTERS | BOMBERS | HELICOPTERS |
|---|---|---|
| MIG-19 FARMER | TU-95 BEAR | MI-24 HIND |
| MIG-21 FISHBED | IL-28 BEAGLE | MI-8 HIP |
| MIG-23 FLOGGER | YAK-28 BREWER | MI-6 HOOK |
| MIG-25 FOXBAT | TU-16 BREWER | MI-4 HOUND |
| SU-7 FITTER | TU-22 BLINDER | |
| TU-128 FIDDLER | TU- BACKFIRE | |
| SU-11 FLAGON | | |
| SU-19 FENCER | | |
| F-9 FANTAN | | |

FIGURE 4-4

# ELECTRONIC WARFARE SCORING
## (COMMUNICATIONS)

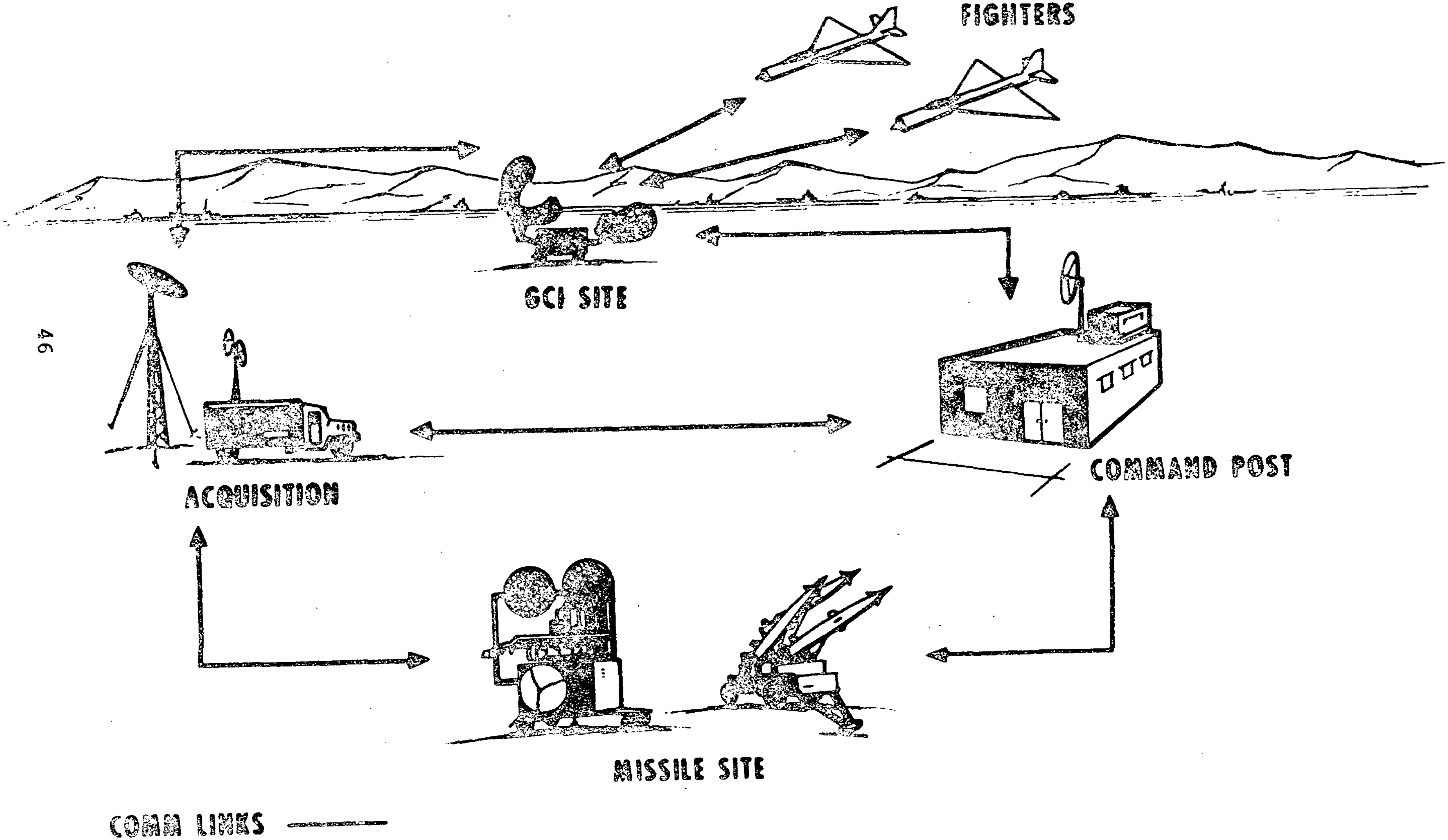
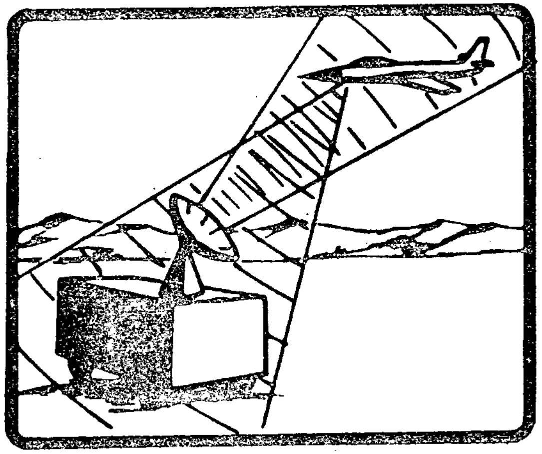
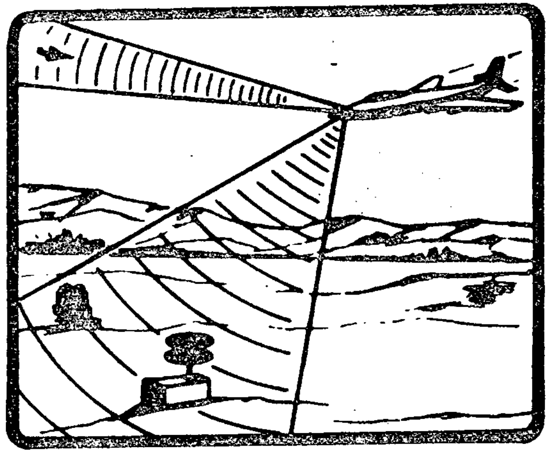



Figure 4-5

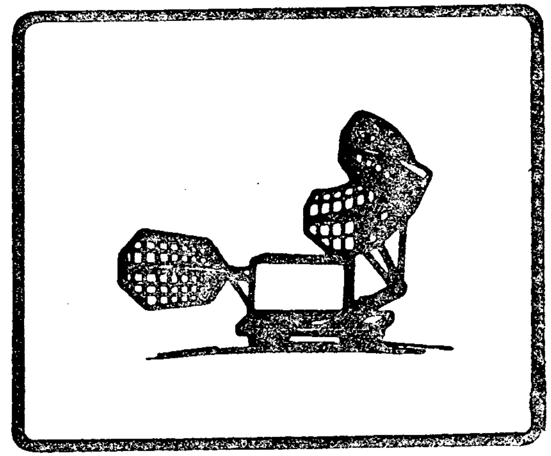
# ELECTRONIC WARFARE SCORING



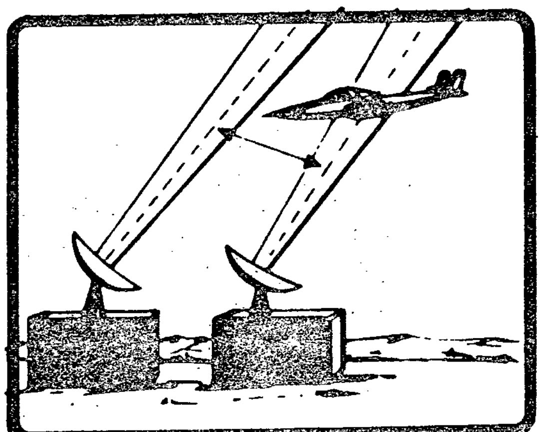
FIRE CONTROL



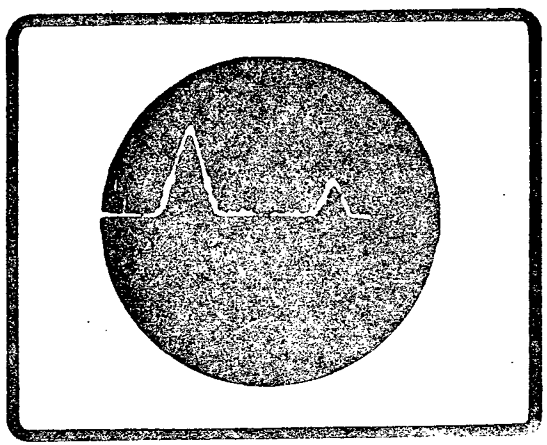
ACQUISITION



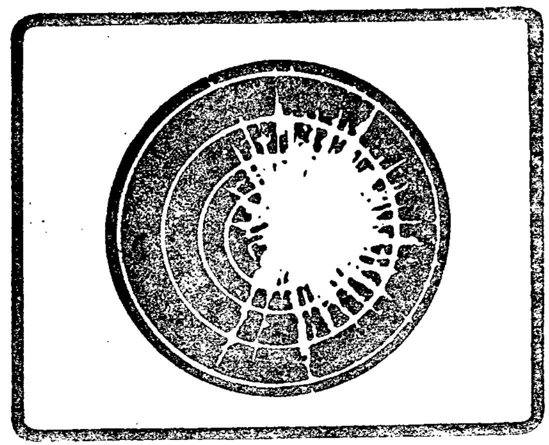
EARLY WARNING



APPARENT vs TRUE POSITION



JAMMING vs SIGNAL



JAMMING EFFECTS

Figure 4-6

air defense SAM or AAA fire and relative missile and aircraft attitudes. Most of the other events associated with the engagement are useful primarily in explaining the "why" for the aircraft attrition. Nevertheless, scoring on the basis of key events may be the primary source of EW effectiveness evaluation until miss-distance scoring can be implemented for the fire control radars. In the following, the principal events and the associated measures of effectiveness are identified, in the order in which they would occur in a typical strike mission. Note that the most important measure of effectiveness is at the end, aircraft attrition. In general, the measures of effectiveness would be relative to either operation without EW or to some baseline EW system. While not specifically identified, events associated with air defense use of ECM against the Blue strike force must also be noted; e.g., jamming of terrain avoidance radar or command and control communications.

a. <u>Detection and Identification of Threat Radar Signals by Aircraft Electronic Support Measures (ESM) Equipment (Early Warning, Acquisition or Fire Control Radars)</u>

- Range at which early warning/acquisition radars are identified.

- Range at which threatening fire control radars are identified.

- Delay time between activation of successive modes on a fire control radar; e.g., missile launch/track, and ESM identification.

b. <u>Evasive Action by Aircraft</u>; e.g., to avoid detection or to cause miss by SAM/AAA.

- Delayed detection range.

- SAM/AAA miss distance.

c. <u>Initiation of ECM Activity by Aircraft</u>; e.g., against early warning/acquisition radar, fire control radar or communications.

- Delay in transmission of track and/or target assignment information.

- Delay in detection/track by SAM/AAA acquisition radar.

- Delay in detection/track by SAM/AAA fire control radar.

- SAM/AAA miss distance.

d. <u>Aircraft Detection/Track by Air Defense Early Warning/Acquisition Radars</u>

- Number of strike and support aircraft (and other aircraft and fake targets) tracked by early warning and/or acquisition radars.

- Delay in transmission of track information to ADWOC.

- Delay in acquisition of assigned target aircraft by SAM/AAA acquisition radar.

e. <u>Air Defense Identification of Track as Hostile</u>

- Fraction of strike and support aircraft (and other aircraft and false targets) assigned hostile track ID.

- Delay in hostile track identification.

f. <u>Assignment of Targets to Red Interceptors</u>

- Delay in assigning target aircraft.

- Accuracy of GCI.

g. <u>Assignment of Aircraft Target to Air Defense Regiment</u>

- Fraction of aircraft designated as targets to SAM/AAA regiments.

- Delay in assigning target aircraft to regiment.

h. <u>Assignment of Target Aircraft to SAM/AAA Battalion</u>

- Fraction of aircraft targets designated to SAM/AAA battalions.

- Delay in assigning target aircraft to SAM/AAA battalion.

i. <u>Aircraft within Weapon Range of an Operational SAM/AAA Weapon System (which has been designated to engage the aircraft).</u>

- Fraction of aircraft exposed to SAM/AAAs.

j. <u>Air Strike Against SAM/AAA Elements</u>

- Attrition of SAM/AAA elements.

- Residual SAM/AAA effectiveness.

k. <u>Launch of Anti-Radiation Missile (ARM) by Aircraft Against Air Defense Fire Control Radar</u>

- Decrease in aircraft exposure time to "active" fire control radar.

- Number of SAM/AAA fire control radars killed (depends both on ARM performance and defense reaction to ARM). (The effectiveness measure should be continued to include weighting on the basis of the relative importance of each radar.)

l. <u>Track Establishment by SAM or AAA Fire Control System (Radar or Optical) Sufficient to Initiate Fire</u>

- Delay in acquisition/track of assigned target aircraft.

- Percentage of time an exposed aircraft is tracked.

- Percentage of aircraft tracked by SAM/AAA fire control systems.

- Accuracy of acquisition data passed to SAM/AAA radars.

m. <u>SAM Missile Launch or AAA Fire Against Target Aircraft</u>

- Percentage of aircraft engaged.

- Number of SAMs launched or AAA expended.

- Delay in SAM launch or AAA fire.

n. <u>Aircraft Kill by SAM/AAAs</u>

- SAM/AAA miss distance.

- Percentage of aircraft destroyed.

Implementation/determination of the above measures of effectiveness (MOEs) is straightforward except for those associated with ARM launch and the SAM/AAA miss distance. Those are complicated by the fact that the ARM/SAM/AAA firings and flight profiles are simulated; i.e., not actual firings during the aircraft/air defense engagement. Aircraft evasive action to SAMs has, in the past, depended strongly on visual observation of the SAM, while the SAM system reaction to an ARM may depend on radar or visual detection of the ARM. It may be possible to provide simulated indications of the ARM launch to the affected SAM/AAA element.

o. <u>Other Measures</u>. Other items, some of which are directly related to the measures of effectiveness, that should be determined or recorded include:

- Video recordings of air defense displays showing the effects of ECM and defense ECCM. These recordings would be useful for post-mission review and pilot debriefings.

- Jamming-Signal ratio measurement at threat radars and/or communications receivers. This data will be useful in determining why certain values for measures of effectiveness were obtained.

- Comparison of early warning/acquisition radar tracks with TSPI data. Useful in determining the accuracy of radar tracking, and in quantifying false track or no track conditions.

- Induced error rates on Integrated Air Defense System (IADS) communications links. This is a measure of the effectiveness of communications jamming. The effects of the jamming would also affect the appropriate measures of effectiveness noted previously.

- Recording of operator commentary.

- Recording of selected communications links (both Blue and Red).

- Recording of the jamming environment in the terminal areas.

The effectiveness of electronic warfare as a penetration aid to an aircraft strike force is directly related to the degradation of critical functions within an Integrated Air Defense System.

Degradation within the Integrated Air Defense System occurs within the following key elements:

- Surveillance network.

- Command and Control.

- Communications.

- Terminal threat acquisition/tracking.

- Terminal threat weapons.

4.6.1.2 Surveillance Radars

A test and training range may have a requirement to determine the contribution of electronic warfare in degrading the effectiveness of early warning, acquisition, height finder and surveillance radars in accomplishing their function in the Red system structure. These

radars initiate track information which is used throughout any defense system and a measure of EW effectiveness against this segment is essential in any overall exercise evaluation.

a. Data Requirements. The EW effectiveness evaluations must be implemented such that results derived from the evaluations do not lead to erroneous conclusions on the part of test analyst and users as to the effectiveness of jammers and EW tactics on the defense system scenario. The following data should be available upon which to base EW effectiveness for the surveillance radars:

- TSPI.
- Radar status data.
- Operator track information.
- IFF performance.

Collateral support data includes:

- Terrain masking.
- Radar coverage.
- Radar antenna data.
- Target cross section.
- Video tape recordings.
- J/S data.

Through use of these data resources, at least a partial evaluation of the effect of electronic warfare on total system performance may be determined. The only true measure of EW effectiveness is to compare losses from GCI and terminal threat systems which are incurred when identical scenarios are run with and without ECM.

b. Candidate System Description. The EW effectiveness evaluation system for the radar systems will be based upon a computation capability at each

radar and the EW effectiveness evaluation system must be capable of the following operations:

- Correlate available point targets with targets acquired and tracked by the radar and operator.

- Measure the jamming to signal (J/S) ratio about each target.

- Maintain a time and event history summary for each target within the range of the radar and terminal system.

- Pass the resulting evaluation data to the next higher echelon of the EW effectiveness evaluation system for correlation and use by that system as inputs for subsequent evaluations. Figure 4-7 depicts the typical signal flow diagram of the EW effectiveness evaluation system and the data required, computing support system capability, and result files available.

To assist in EW effectiveness evaluations and training, a video tape recording system can be integrated into each radar system. The video recording system would have a playback mode to enable training, briefing, and debriefing of system operators, analysts, and range users.

c. Alternate Approaches. An alternate approach to achieving a measure of EW effectiveness would be to perform post-mission analysis. The major problem in this approach is that real-time correlation with other range events cannot be accomplished. Specifically, evaluations of system performance may be jeopardized by inabilities to remove participants from the scenario and interject this data into the acquisition process. The ability to remove targets in an improved system operation is readily implemented. The post-mission analysis approach could be utilized initially where there is no real time processing capability at each radar.

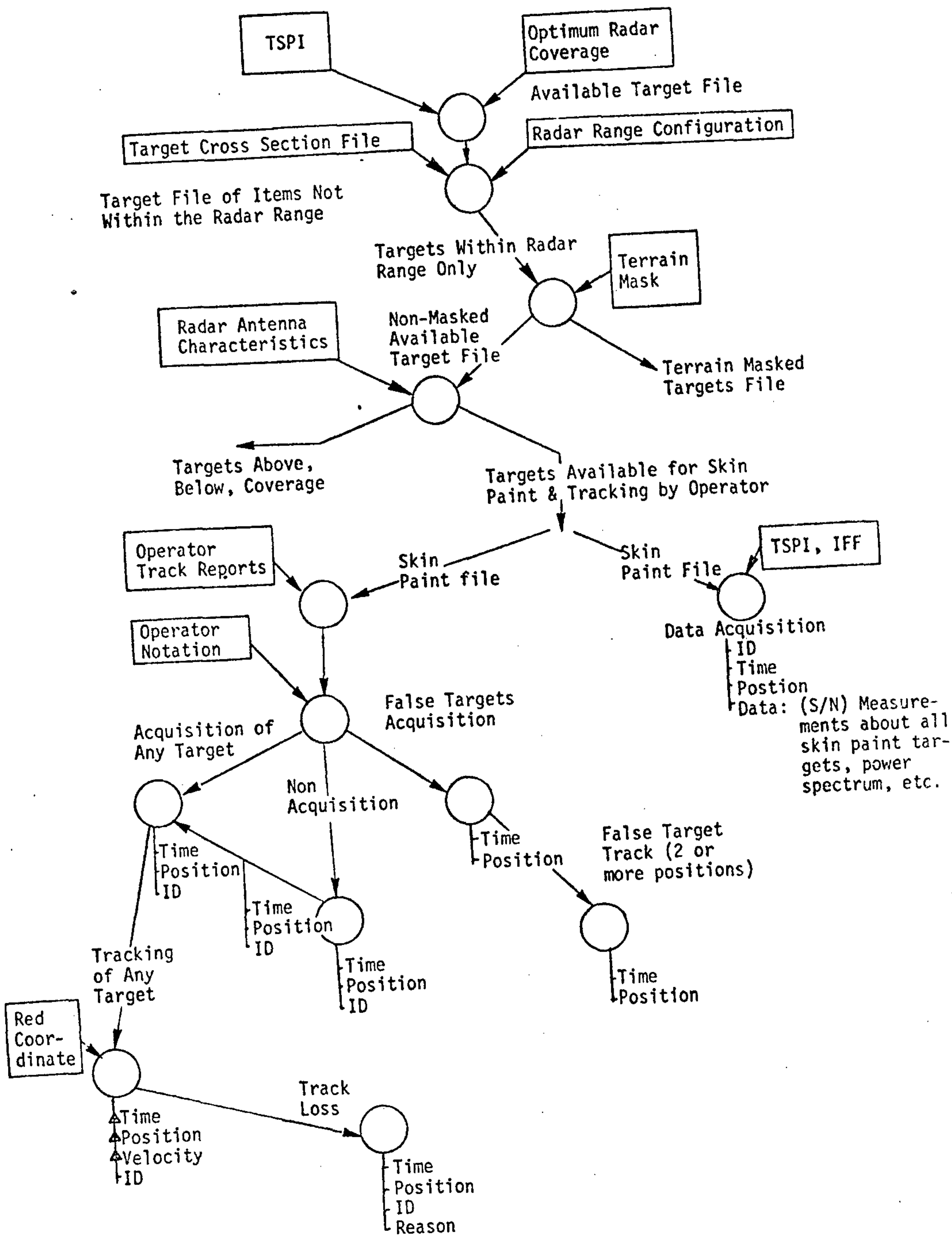



Figure 4-7

EW FLOW DIAGRAM

d. Considerations. A primary technical consideration is in proper sizing of the remote computer system at each radar to handle the EW effectiveness evaluation, GCI capability, and the IADS semiautomatic $C^3$ capability. If necessary, remote collocated vans to handle these functions must be provided and interfaced at the common data point. The remote vans concept is in harmony with actual policies under which system improvements are added as separate units with minimum modification to existing hardware.

e. Recommendations. It will be necessary to evolve the EW scoring system which initially will be based upon recording of event data and post-mission analysis. However, with the incorporation of a semiautomatic IADS system, real-time remote computation, data acquisition and EW effectiveness evaluations will be possible. The modifications to existing hardware could be initiated by incorporation of an electronic warfare common data point to the existing instrumentation common data point. This system would be a parallel signal processing receiver using only the radar local oscillator and adding separate IF sections (without ECCM measures). The signal output from this parallel receiver section may be used to measure the following items:

- Jammer power level and spectrum.

- Signal-to-noise ratio.

In addition, measurement and signal processing equipment will be used to:

- Determine jammer status (off-on).

- Determine the jammer identification in conjunction with the frequency spectrum surveillance system.

#### 4.6.1.3 Command and Control System

Air defense command and control functions might be disrupted or degraded either through noise jamming or by

introduction of erroneous data into the command and control structure (deception jamming). Similar degradation of Blue command and control might occur due to Red Force use of ECM. ECM action is intended to cause one or more of the following operational problems:

- Delays in passing air situation track data.

- Delays in making and passing operational decisions and directives.

- Accuracy in receptions and data transfer.

a. Candidate System Description. The EW effectiveness evaluation system for the command and control structure can be based only upon measuring the accuracy and correlation of transferred data and not upon the decisions which are made. The evaluation would be based upon noting the following at each decision element within the air defense system.

- Correlation of multiple inputs to effectiveness in passing singular outputs.

- Through-put delays.

- Accuracy of position and velocity of outputs.

- False/valid tracks passed into the system.

- False/valid tracks generated by the system.

- False/valid tracks picked up by the system.

- False/valid tracks output from the system.

- False/valid tracks dropped by the system.

Associated with the above data, accuracy in reception and transfer of track and target data and associated delays in passing track information and in making and passing operational directions must also be assessed.

b. Communcations Scoring. Experience indicates that defense command and control functions can be disrupted by degrading or eliminating communications through ECM action. Blue communications should also be subjected to realistic ECM action to allow evaluation of susceptibility.

c. Candidate System Description. The defense communications system is a set of radio and microwave links interconnecting the surveillance, command, control and terminal threat systems over which digital and voice data is transferred. Degradation of the command, control system as a function of communications jamming can be evaluated in terms of reduced information capacity, delays in message transmission, reception of erroneous or confusing messages and errors in digital data transmission. Blue command and control performance in an ECM environment can be evaluated in analogous fashion. The proposed system is outlined below:

- Digital Links. Measurement of bit error rates.

- Voice/Video Links. Operator notation as to the quality of reception.

- Alternates. An alternate system could be implemented to provide an interference-free channel to permit numerical evaluation of the jammed channel performance as compared to the interference free channel output.

d. Recommendations. It will be necessary to evolve the communications scoring system based upon basic requirements and the task for both manual systems and the expansion of the associated semiautomatic defense system. Radio signal reporting codes denoting signal strength, interference, noise, modulation disturbance, frequency of fading, modulation quality and depth and frequency of message repeats will be tabulated as needed for each transmission of voice, data, and teletype messages. Software modifications could

provide a real-time log of digital error rates, and key set inputs to the data acquisition system for reporting the quality of voice and video reception.

- Key Sets. Key sets for manual input of signal reception quality must be provided to each operator.

- Computer System. Capability to determine and tabulate bit error rates must be incorporated into each modem I/O channel.

4.6.1.4 Terminal Threat Acquisition

There exists a number of measures of effectiveness appropriate to an evaluation of the effect of EW on a SAM or AAA battery and various supporting measurements and/or recordings that should be made. Events appropriate to SAM or AAA battery, for which the occurrence and times should be noted, include:

a. Assignment of target aircraft.

b. Position and velocity errors in assignment.

c. Assigned target aircraft within weapon range.

d. Fire control radar on.

e. Track established.

f. Track established valid with assignment.

g. SAM launch or AAA fire.

h. Track lost.

i. Target disengaged.

j. Onset of jamming.

k. ECCM action.

l. ARM detection/warning received.

m. Fire control radar off.

All of these can be treated as functions which are routinely transmitted by an on-site scoring system for real-time use and/or recording. Other functions such as "switchology" functions which are recorded and transferred, include: radar pulse repetition frequency (PRF); gain setting, azimuth, elevation and range to target aircraft; radar mode (e.g., Track While Scan (TWS), Lobe On Receiver Only (LORO); dish mode) and range settings. Operator comments should also be recorded to provide a valuable augmentation where events or reactions to events are uncertain.

a. <u>Defense System Description</u>. The terminal threat defense system is a set of SAM and AAA elements and various supporting systems. Degradation in the effectiveness of these systems to perform their tasks is initially evident from degradation in the following items:

- Accuracy of position and velocity of assigned targets.

- Ability to acquire and track assigned targets whether assigned or as targets of opportunity.

- Validity in tracking correct targets.

- Ability to correlate a separate false track and valid track when targets are acquired.

Associated with the above data, accuracy in reception and transfer of track data to subordinate terminal threat systems, and associated delays in passing track information and in making and passing operational direction must be denoted.

b. <u>Candidate Systems</u>

1) <u>Computer Assist</u>. Use of a computer to separate the data when Range TSPI and radar parameters

are known in conjunction with track data passed to the element. The principal problem with using the computer system is that digital data representing tracks passed to the system are necessary along with an external range TSPI system.

2) Video Recordings. Video recordings of radar video for post-mission scoring of the acquisition and tracking portion of the terminal phase could be used.

3) Recommendations. The video recording system will permit post-mission analysis of the ability of the operator to acquire and track a target. With external TSPI for terminal threat scoring, the resolution to which a track is established and maintained will be known, and real-time scoring will be possible. Post-mission analysis to determine the validity, and ability to separate false tracks, accuracy of position and velocity of assigned target, and associated system delays will be required.

### 4.6.1.5 Terminal Threat Scoring

The ultimate measure of effectiveness of EW against an air defense is the success (or degree of success) of the mission; i.e., was the aircraft (or strike force) able to successfully penetrate to its weapons release point? Evaluating this measure of effectiveness involves a determination of the probability of kill or SAM and/or AAA firings against the aircraft (or strike force). Two basic options are available:

a. Record events, flight profiles, etc., and through post-mission analysis, derive estimates of defense element attrition and aircraft attrition. The post-mission analysis would then be done via use of simulations; e.g., the Air Force Electronic Warfare Evaluation Simulator (AFEWES) and Tactical Air Defense Battle Model (TADBM, a modified version of the Air Force Tactical Digital Model). The primary difficulties are the long post-mission analysis time before results are known and the lack of realism engendered in doing kill removal after the fact; e.g.,

an aircraft "killed" early in the engagement still completes the mission, including use of ECM against subsequent air defense elements.

b. Incorporate real-time (or near real-time) miss distance determination (and subsequent kill probability calculation) into the instrumentation for simulated ground-to-air scoring at the site. Two alternatives can be considered for implementing miss distance scoring: use of a tracking system external to the threat fire control radar (e.g., TSPI) or use of a tracking system essentially integral to the threat radar (i.e., mounted on the same pedestal). Both techniques would require computer simulation of the SAM or AAA trajectory, etc., in response to guidance and/or commands from the corresponding fire control radar.

1) System Elements. The terminal threat scoring system would incorporate the following items to enable evaluation of EW effects upon the terminal threat system performance.

- On-site scoring evaluations with only the results transmitted to a Range Control Center.

- Missile track loops.

- TSPI for implementing miss distance scoring.

2) Candidate Systems. The basic alternatives for implementing ground-to-air scoring are:

- Use of external TESPI for target tracking.

- Use of a tracking system which is an integral part of the threat radar.

a) Considerations. Use of the TSPI for scoring ground-to-air requires that the TSPI and fire control radar be "registered" into the same coordinate system (i.e., calibrated) for SAM/AAA trajectory simulation and control (command from radar). Achieving

this is complicated by the fact that threat radars are frequently moved and set up for operation on crudely prepared sites. Even if rarely moved, and operated from concrete pads, the problem of achieving sufficiently accurate registration has been a problem in the past. Great care should be taken in this matter and reference is made to the later section 4.6.8.1, Calibration.

b) A scoring system approach where the target TSPI is incorporated as an integral portion of the threat radar could include the following approaches:

- IFF.
- Optical (passive).
- Laser.
- Mixture of optical and laser systems.
- Transponder.
- Radar.

Disadvantages of one or another of these approaches include:

- Eye Safety Problem.
- Dynamic effects upon the threat system.
- Shadowing of transponders.
- Requirement for cooperative transponders on aircraft.
- Contrast ratio problem of targets against a horizon (horizon crossings).
- Target registration.
- PRF matching problems.
- Jamming by EW systems.

c. Candidates. A matrix summary of candidates and criteria considered is shown on Table 4.1. The matrix shows the parameters and trade-offs for providing TSPI for EW scoring from a central range TSPI system and a local TSPI system dedicated to an individual threat system. A separate local TSPI is desirable for use with small training missions consisting of one to four ship flights, particularly if the system does not require an aircraft pod. A comparison of the various techniques indicates that for a range TSPI system covering large EW exercises the multilateration system appears to be the best since it will handle large numbers of participants. However, it requires that pods be carried by the aircraft and, depending on the operations frequency, could encounter interference from jammers during an EW exercise. Radar TSPI systems for large exercises present a major problem in that they are essentially one-on-one trackers so that a larger number of radars would be required. The Global Positioning System (GPS) is promising as a range TSPI system; however, it will not be available until the 1978-1980 period. The IFF system can track a large number of participants but does not provide the accuracy required for miss distance EW scoring.

In comparing local TSPI systems, the K-band ON-AXIS radar appears advantageous provided enough power can be obtained to operate at the ranges required. Some degradation of radar performance will occur during severe fog or rain conditions. The major advantage of the K-band radar is that it will not now interfere with the aircraft RHAW equipment. Optical tracking techniques can be used; however, optics are not all weather. Laser systems with sufficient power to score at the ranges required are potentially dangerous to humans. Local IFF cannot provide the accuracy required for EW scoring. A multilateration system appears to provide the most promising system for range TSPI for EW scoring and ON-AXIS radar, preferable in the K-band range, shows the most promise for local TSPI scoring for EW.

EW TSPI MATRIX

Table 4.1

| | All Weather | Real Time | Range | Accuracy | Error Model | # Participants | Mobility | Require Pods | EW Interference | Comm Net |
|---|---|---|---|---|---|---|---|---|---|---|
| RANGE TSPI | | | | | | | | | | |
| Multilateration | YES | YES | YES | YES | YES | YES | Area Coverage | YES | Potential | YES |
| Radar | SOME LIMITATION | YES | YES | YES | YES | One/one | YES | NO | K Band-NO | YES |
| GPS | YES | YES | YES | ? | ? | YES | AREA | AC MOD | NO | YES |
| IFF | YES | YES | YES | NO | - | YES | AREA | NO | NO | YES |
| LOCAL TSPI | | | | | | | | | | |
| L-Band on-axis Radar | K-BAND LIMITATION | YES | YES | YES | YES | One/one | YES | NO | NO | NO |
| Optic Tracking | NO | YES | T-13 ONLY | YES | YES | One/one | YES | NO | NO | NO |
| Mix Laser Optics | NO | YES | T-12 ONLY | YES | YES | One/one | YES | NO | NO | NO |
| Local IFF | YES | YES | YES | NO | NO | One/one | YES | NO | NO | NO |

It should be realized that all radio class TSPI systems have vulnerability to jamming signals, and that as new jamming frequencies are required in the EW arena, problems will arise with respect to TSPI systems and corrective action will be required.

d. Video Record/Playback and Display. The evaluation of EW effectiveness for several simultaneous EW engagements of Blue forces against combinations of threat systems may be accomplished on some of the ranges. In conjunction with digital analysis for determining EW pilot training, mission review and EW briefing reviews and presentations, adeqauate recording of displays communications, and related matter are required.

1) System Description. The recording system must be capable of recording the following data:

- Operator video.
- IFF.
- Switchology.
- Voice data.
- Time.
- Digital data.

Such a system is contemplated at the radar or other data acquisition center. Recording may be done on a single recorder having the required number of channels including video or alternatively, may be done on several separate time synchronized recorders.

2) Alternative. As an alternate to recording video at the radar for White instrument action purposes, video data could be microwaved to a Range Control Center for recording and display. However, the video remoting for White instrumentation would require considerable bandwidth in the communications system. Also, the system would not lend itself to on-site display capability for operator training at the radar.

4.6.2 Aircraft Communications Evaluation System (ACES). (Figure 4-8)

4.6.2.1 General

a. The impact of the hostile Ground Controlled Interceptor (GCI) aircraft in a broad category of USAF aircraft mission objectives has been estimated based exclusively upon the results of analytical and laboratory hardware simulations.

b. A portion of the GCI system (except for on-board aircraft weapons and guidance equipment) deals exclusively with ground based mid-course guidance to place the GCI aircraft in the area where visual or airborne radar contract enables terminal intercept to begin.

4.6.2.2 GCI System

The mid-course guidance system is in general composed of grounded based radars, command and control elements; aircraft display and control systems, and communications equipment.

4.6.2.3 ACES Function

The intent of the ACES program is to develop, integrate and deploy in a modular growth sequence an operational GCI intercept simulator system to establish a multi-purpose GCI operational "Test Bed." The initial phase of this program is to develop equipment replicating the communications equipment with a companion Electronic Warfare Scoring System to assess the impact of communications countermeasures upon the GCI process. The associated figure depicts the ACES program elements including a proposed EW scoring system.

4.6.2.4 Program Phases

Follow-on phases of the ACES program would encompass development and integration of systems for aircraft and ground based equipment. Specifically, these elements

# AIRCRAFT COMMUNICATION EVALUATION SYSTEM (ACES)

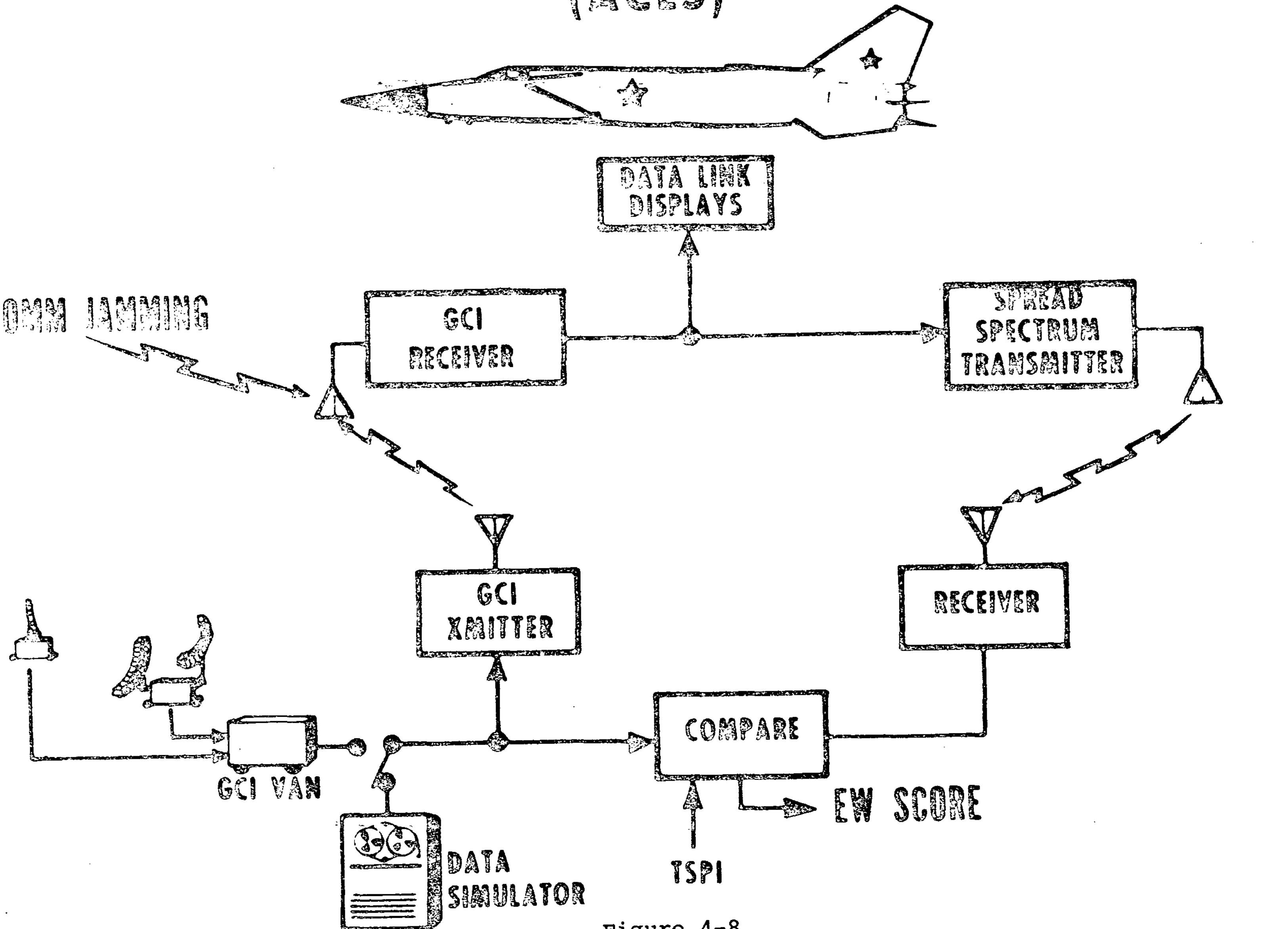



Figure 4-8

include manned command and control equipment, cockpit displays and existing threat radar systems integration.

4.6.2.5 OTT&E Integration

Upon completion of the ACES development program, utilization of the existing USAF air combat maneuvering instrumentation (ACMI) and associated simulated weapons systems, end-game analysis incorporating up to 20 participants would be possible.

4.6.2.6 Conclusion

The ACES program would provide a threat simulator capability not presently available for operational use in any comprehensive operational form.

4.6.3 Scoring for Simulated Launch/Release (Figures 4-9, 4-10, 4-11, 4-12 and 4-13)

4.6.3.1 Introduction and Scoring Definitions

The goal of this segment is to provide a capability to score simulated launches/releases. Again the process starts with the requirements definition phase. This phase identifies what the range user will ask the instrumentation to provide and what decisions will be made based on the answer. Included in this phase is the basic choice of an acceptable scoring technique. Four types of scoring for simulated weapons have evolved historically; they are described below in generally ascending order of accuracy, complexity, and cost.

a. Exposure Envelope Scoring. Basically, exposure envelope scoring records the time intervals in a mission during which any given target is within the line-of-sight of an given threat. The threats may include observors, acoustic sensors, radars, lasers, etc. Sophistication may be added by requiring the target to be within a given range of the threat, or within a given range-altitude-relative velocity envelope. Whatever these added requirements, they would be imposed to simulate sensor capabilities and/or the limitations of threat weapons associated with the sensors. Exposure envelope scoring is thus a very simple method of simulating weapons effects. This method requires little or no special equipment and is low cost.

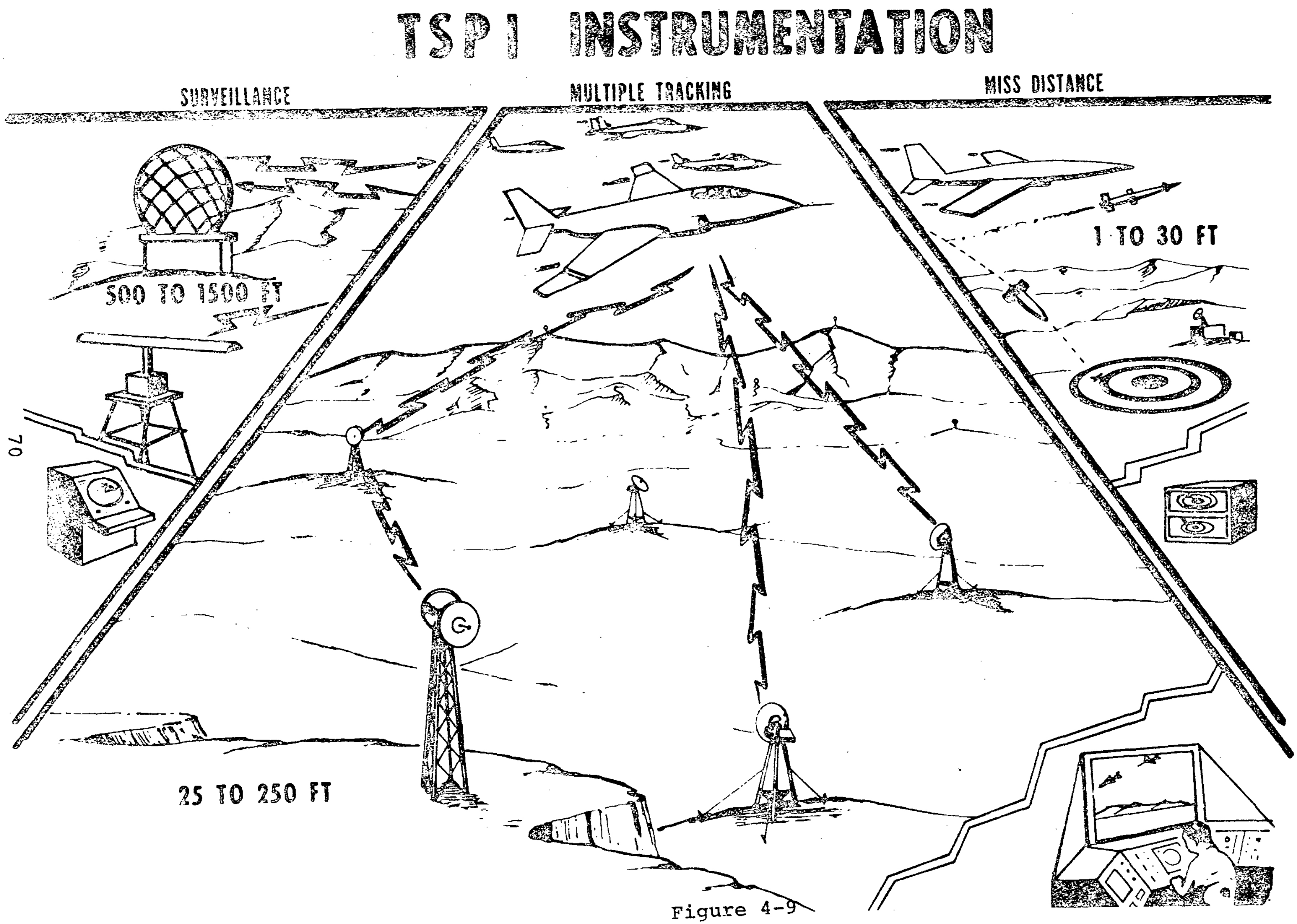

TSPI INSTRUMENTATION
SURVEILLANCE
MULTIPLE TRACKING
MISS DISTANCE
500 TO 1500 FT
25 TO 250 FT
1 TO 30 FT

Figure 4-9

# POSITION MEASURING INSTRUMENT SYSTEMS

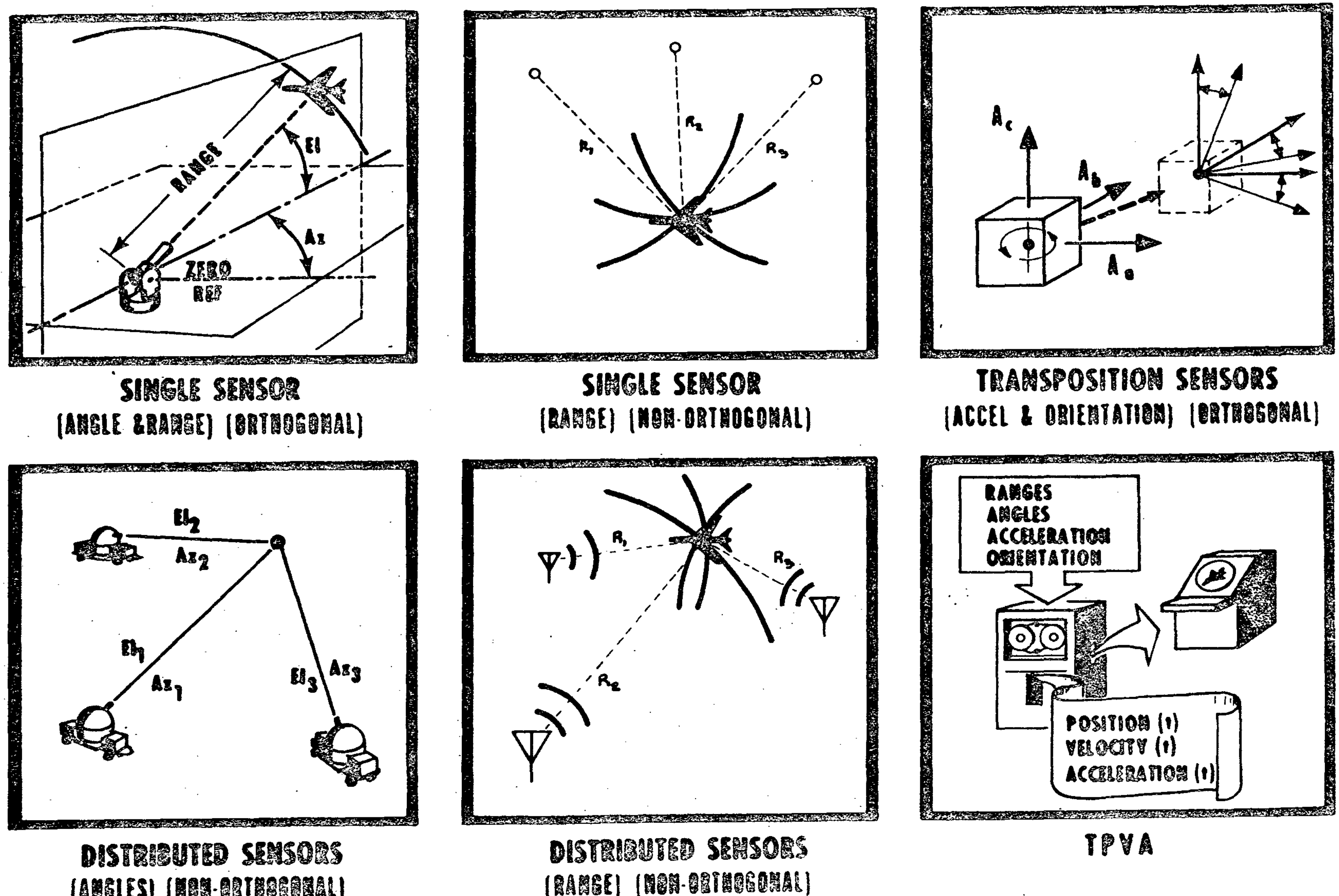



Figure 4-10

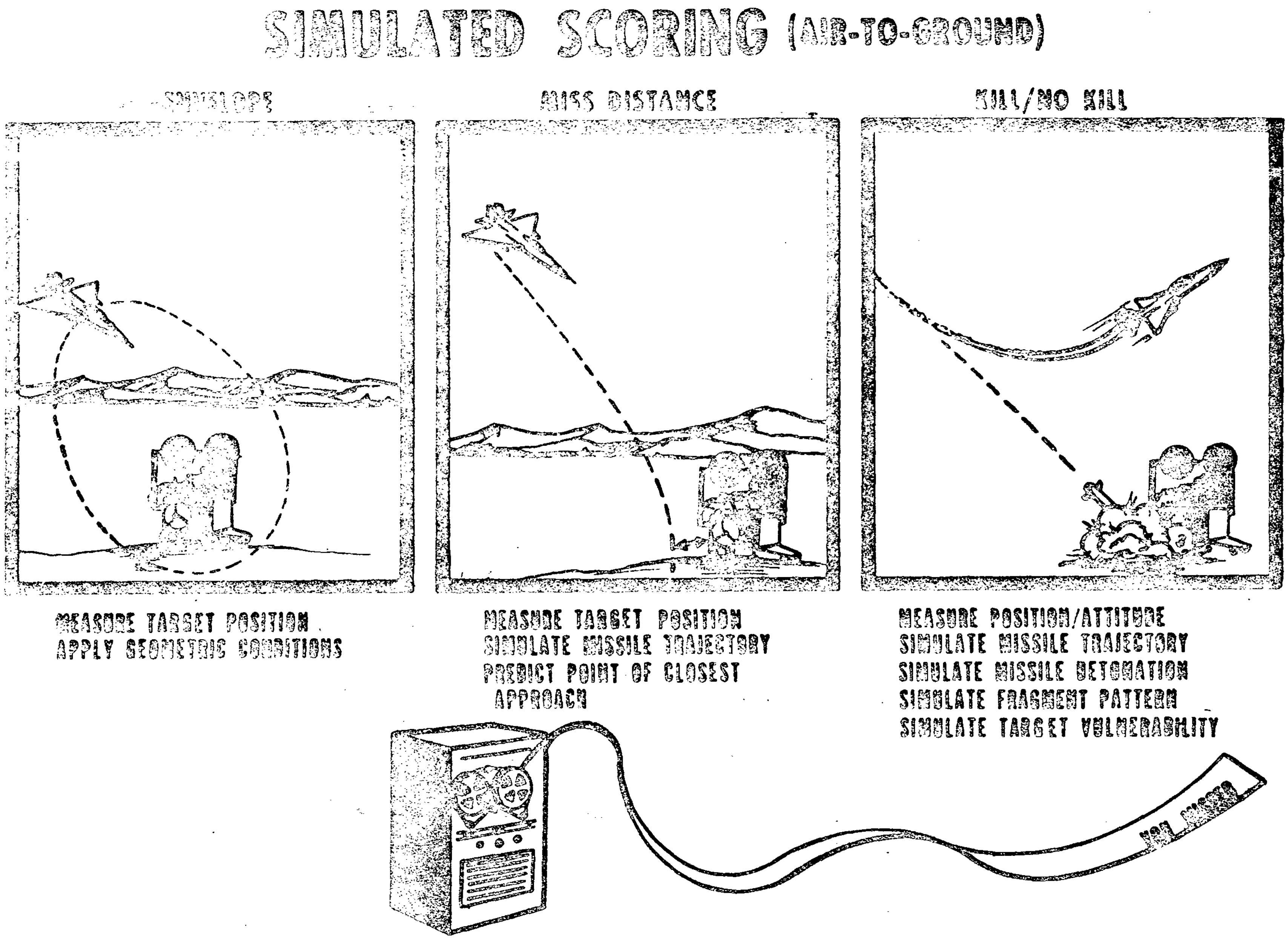

SIMULATED SCORING (AIR-TO-GROUND)
MISS DISTANCE
KILL/NO KILL
MEASURE TARGET POSITION
APPLY GEOMETRIC CONDITIONS
MEASURE TARGET POSITION
SIMULATE MISSILE TRAJECTORY
PREDICT POINT OF CLOSEST APPROACH
MEASURE POSITION/ATTITUDE
SIMULATE MISSILE TRAJECTORY
SIMULATE MISSILE DETONATION
SIMULATE FRAGMENT PATTERN
SIMULATE TARGET VULNERABILITY

Figure 4-11

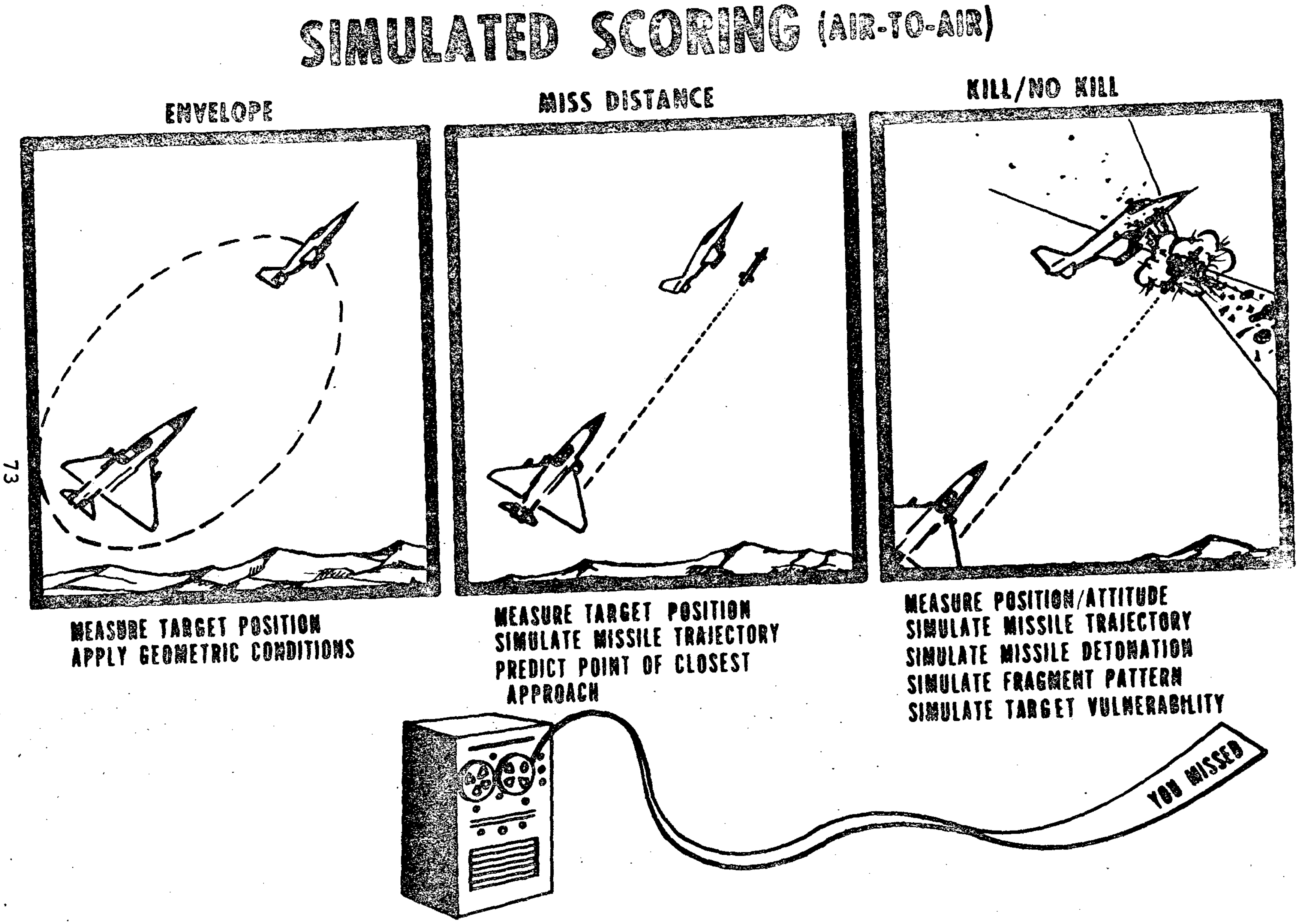

SIMULATED SCORING (AIR-TO-AIR)
ENVELOPE
MISS DISTANCE
KILL/NO KILL
MEASURE TARGET POSITION
APPLY GEOMETRIC CONDITIONS
MEASURE TARGET POSITION
SIMULATE MISSILE TRAJECTORY
PREDICT POINT OF CLOSEST
APPROACH
MEASURE POSITION/ATTITUDE
SIMULATE MISSILE TRAJECTORY
SIMULATE MISSILE DETONATION
SIMULATE FRAGMENT PATTERN
SIMULATE TARGET VULNERABILITY
YOU MISSED

Figure 4-12

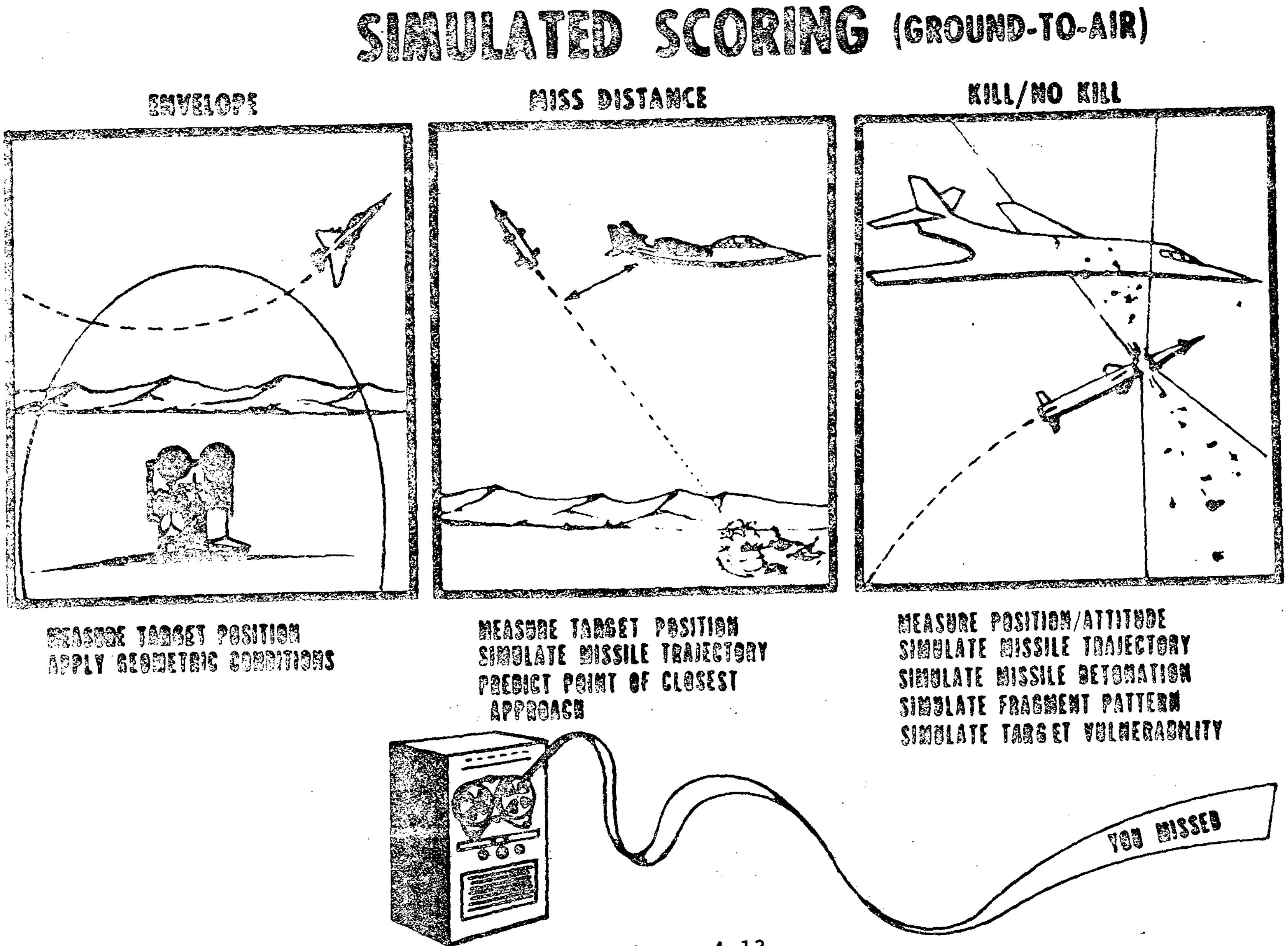

SIMULATED SCORING (GROUND-TO-AIR)
ENVELOPE
MISS DISTANCE
KILL/NO KILL
MEASURE TARGET POSITION
APPLY GEOMETRIC CONDITIONS
MEASURE TARGET POSITION
SIMULATE MISSILE TRAJECTORY
PREDICT POINT OF CLOSEST APPROACH
MEASURE POSITION/ATTITUDE
SIMULATE MISSILE TRAJECTORY
SIMULATE MISSILE DETONATION
SIMULATE FRAGMENT PATTERN
SIMULATE TARGET VULNERABILITY
YOU MISSED

Figure 4-13

b. Miss-Distance Scoring. There are two classifications ofmiss-distance scoring. In scalar miss-distance scoring, the minimum distance between the fired weapon and the target as they pass each other is the measure of effectiveness (the "miss-distance"). This includes zero miss distance for a weapon hitting the target, and it includes the target-to-impact point distance for an impact-detonated weapon aimed at a ground target. Vector miss-distance scoring provides the weapon velocity vector and the miss distance.

For scalar miss-distance scoring, the miss-distance value itself could be the measure of effectiveness. Ordinarily, however, the miss-distance will be related to a weapon lethality radius, probably without regard for target vulnerability characteristics, and the weapon will be considered successful if and only if its target miss-distance is less than the predetermined lethality radius.

The weapon would be considered successful in vector miss-distance scoring if the miss-distance and relative velocity vector fall within a pre-determined lethality envelope. The lethality envelope is a product of the lethality radius, or more properly: the lethality geometry of the warhead; the velocity of the missile; the aspect angle of the missile in relation to the target; and the vulnerability of the target. Each of these ingredients can be neglected, generalized, or detailed depending on the sophistication of the simulation. Greater operational cost and more complex equipment and software are attendant on the more sophistication. However, more realism is attained with more sophistication.

c. Kill-No Kill Scoring. This type of scoring consists of separating each weapon-target interaction into two mutually exclusive categories: (1) the target is completely undamaged and unaffected, and (2) the target is killed immediately. The mechanism for making this separation is subsidiary to the rigidity of the categories. Kill-no kill scoring may differ from miss-distance scoring only in that the words "successful" and "unsuccessful" are replaced respectively by "killed" and "not killed." If more realism

is desired, fuze activation time may be used to determine the location of the warhead at detonation; warhead blast and fragmentation effects at the target may be determined by considering air properties at altitude, weapon and target relative aspects; and relative velocities may be added vectorially to detonation-produced blast wave and fragment velociites. These quantities may then be applied to a geometrically-detailed target vulnerability model to assess target damage. The kind of relationships involved are graphically illustrated in Figure 4-14. At this point, the results may be as realistic as concrete knowledge permits, but some realism will be necessarily lost when the target damage assessment is converted to a kill-no kill scoring choice, rather than acknowledging the range of possibilities noted in the following section.

A distinct advantage of kill-no kill scoring applies to OT&E scenarios for which kill removal is desired to enhance the realism of simulated combat. The target is either quickly, completely removed by a weapon, or it continues its mission at its original performance level. There are thus no requirements for wiring equipment to simulate partial failure, or for training operators to perform as if their equipment were partially damaged.

d. Damage Assessment Scoring. This scoring, ideally, takes advantage of all the sophistication built into real weapons and computerized end-game simulations to estimate the degree and kinds of damage imposed upon a given target by a given weapon. Damage assessment scoring in these cases will be most meaningful if the end-game simulation is the detailed type mentioned in the preceding discussion on kill-no kill scoring.

Within this scoring category, two approaches may be applied. In the first, immediate damage assessment scoring, the degree of target subsystem destruction directly caused by the weapon would be determined. That damage would be translated into a "continue mission" signal, possibly specifying reduced performance, or signals such as "killed" or "return to base" could be given. Scoring would then be recorded, and the next weapon-target interaction would be an independent scoring event.

# KILL/NO KILL DETERMINATION FACTORS

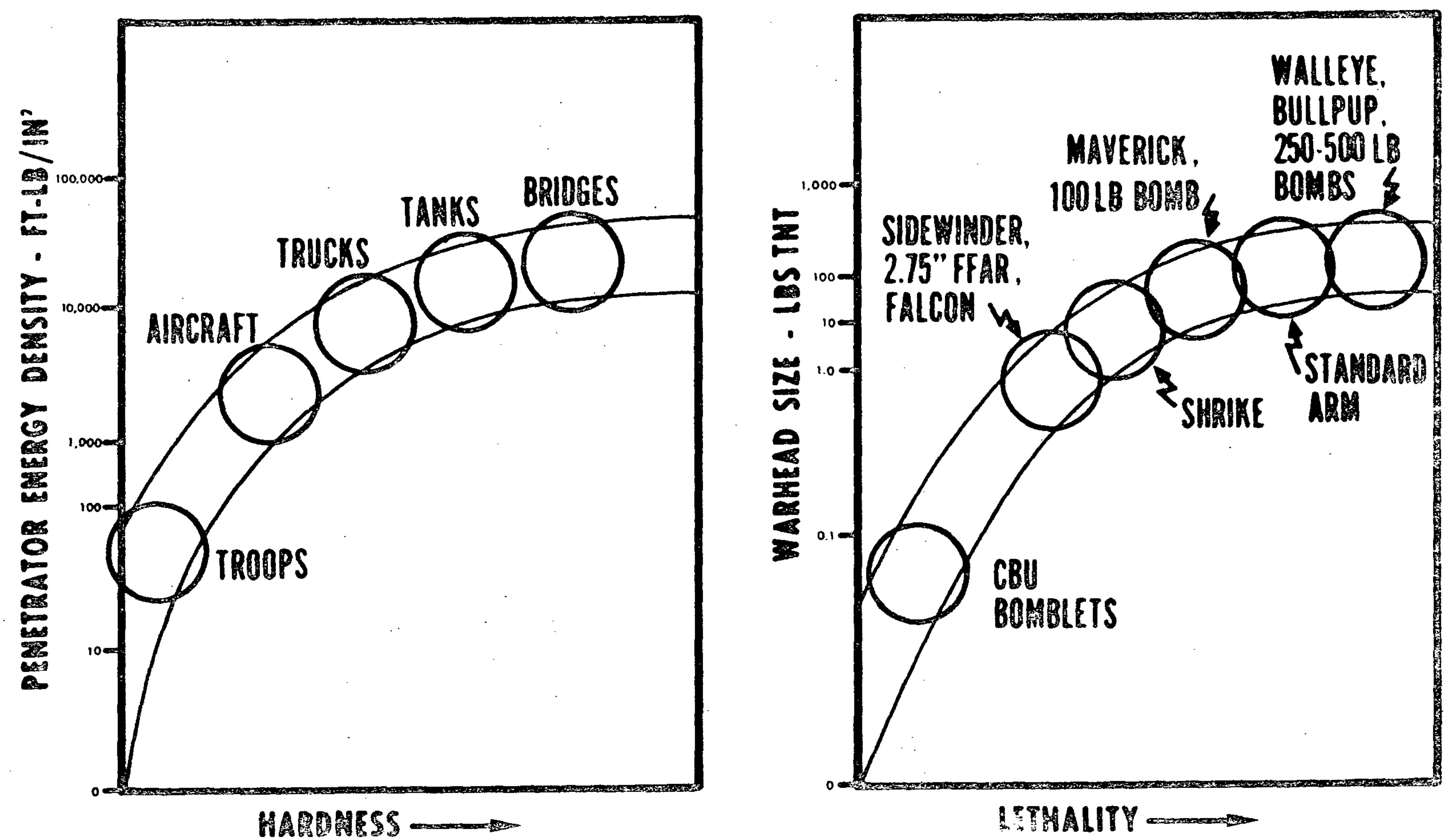



Figure 4-14

In the second, more comprehensive "delayed damage assessment scoring," the scoring computer would track the partially damaged target, determining if damage propagated later was due to newly-imposed mission stresses, or adding damage from subsequent weapons to that of the first. Appropriate damage or kill messages could thus be addressed to the system operator at any time during the mission after the first weapon detonation. Delayed damage assessment scoring is thus the most realistic possible scoring short of actual combat.

There appear to be two major disadvantages to damage assessment scoring. First, compared to other scoring methods it requires the most detailed weapons and target data as input as well as the largest computer facilities to mechanize. Second, the scoring results are realistically varied and therefore more difficult to evaluate than--say--"killed" or "not killed." Both of these considerations imply increased expense and facilities compared to simpler scoring techniques. The costs and facilities required for the highly sophisticated scoring approach must be balanced with those required for a moderately sophisticated or even a simple approach while still providing the required evaluation base for a multi-million dollar OT&E scenario.

4.6.3.2 <u>Accuracy Requirements</u>

The next step is to translate these operationally oriented requirements into instrumentation requirements defining the measurements that must be made and to the degree of accuracy needed to answer the operational questions. Establishing final instrumentation accuracy requirements that will satisfy operational needs and yet are technically achievable is the most critical part of this process. The influences of instrumentation inaccuracies in simulated socring are depicted graphically in Figures 4-15, 4-16, and 4-17.

a. <u>Accuracy Requirements for Unguided Weapons.</u> The Dikewood Corporation, TESPO's Systems Engineering and Technical Assistance (SETA) contractor, has completed studies entitled "Aircraft Flight Parameter Accuracy Requirements for Scoring Simulated Air-to-Ground Unguided Weapons Deliverys," and "Dispersion, Trajectory and Accuracy Considerations for Scoring

# ERROR INFLUENCES IN SIMULATED SCORING
## (GROUND-TO-AIR)

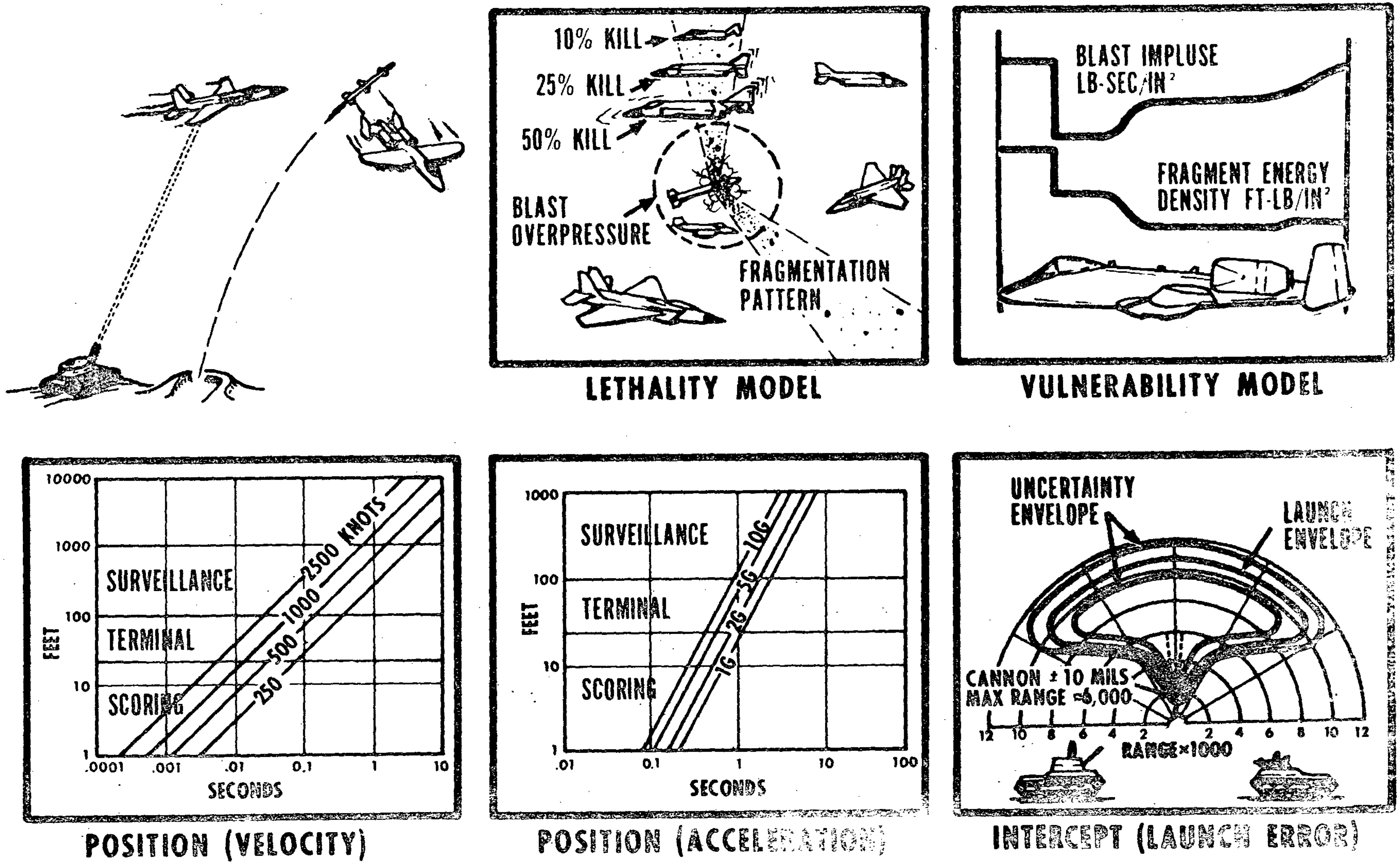



Figure 4-15

# ERROR INFLUENCES IN SIMULATED SCORING
## (AIR-TO-GROUND)

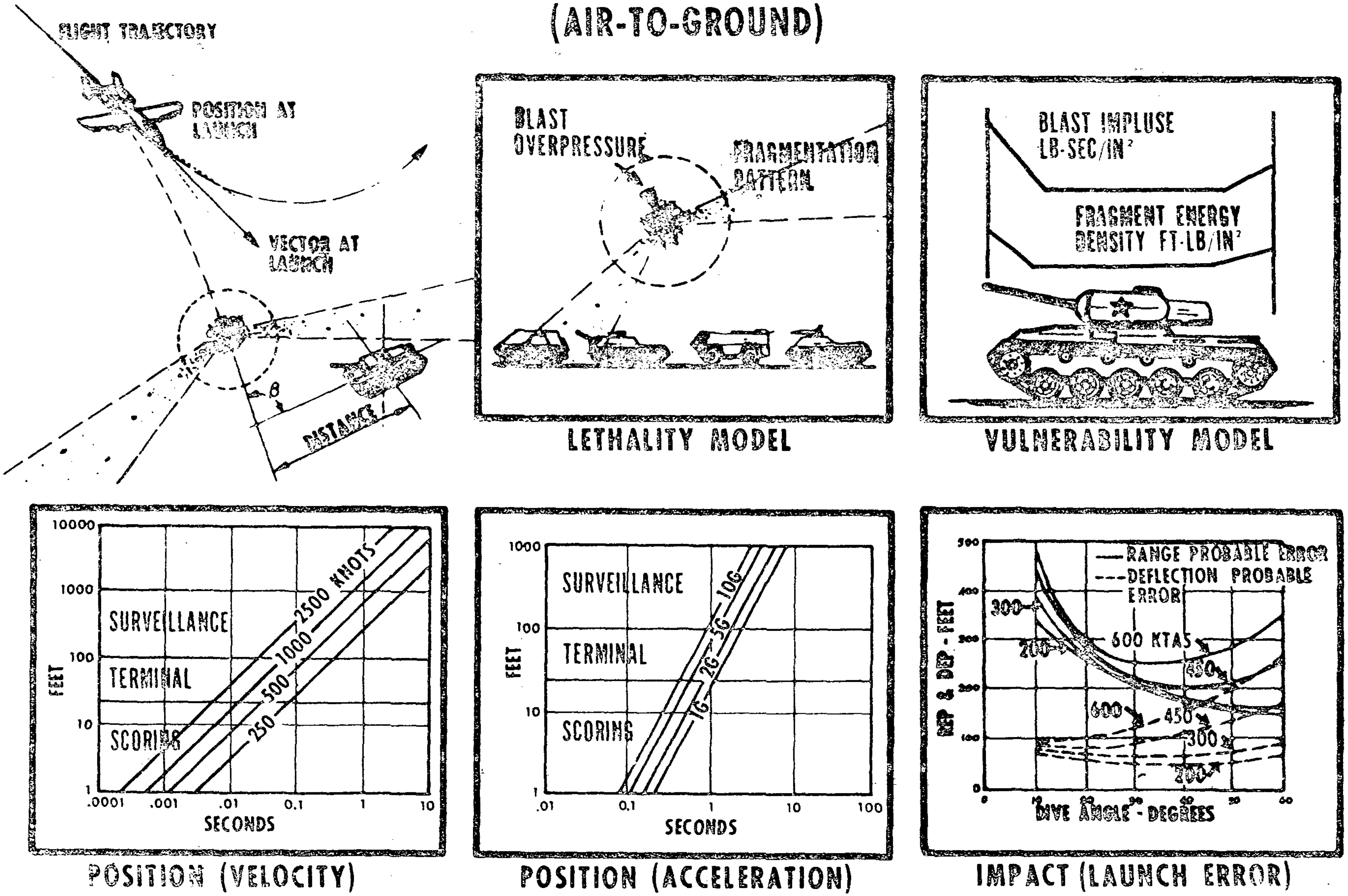



Figure 4-16

# ERROR INFLUENCES IN SIMULATED SCORING

## (AIR-TO-AIR)

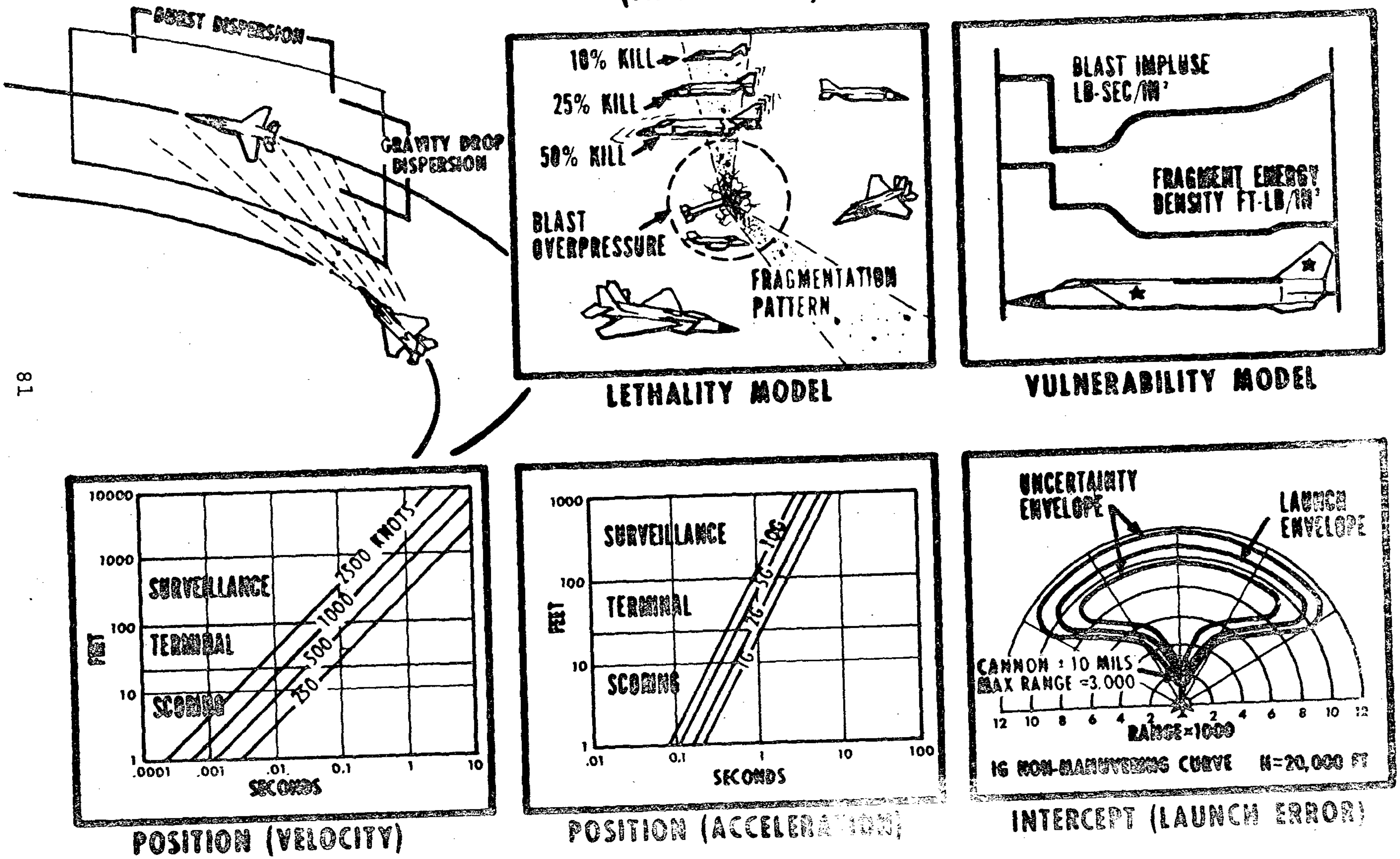



Figure 4-[illegible]

Simulated Gun Bursts in Air Combat." These studies were accomplished to provide tools for relating a desired simulated unguided weapon impact point accuracy to the required accuracies to which launch platform attitude and flight parameters must be known by the instrumentation system at the instant of simulated weapons launch.

b. Scoring System Characteristics for Unguided Weapons. Work accomplished so far has identified eight important characteristics that the nature of test and training scenarios impose on any scoring system (SS) designed to score simulated weapons launches. These are:

- Participants must be defined as attackers, targets, or composites (interchange of roles) before the scenario starts.

- The weapons used must be identified to the SS before they are fired.

- The SS should allow each participant to interact with all the other participants according to its role in the scenario.

- Individual variations in weapon trajectories (including MG and cannon bursts), fuse behavior, and warhead fragment trajectories may never be predicted deterministically.

- Preaveraging the statistical variations in the above paragraph eliminates realistic considerations of manufacturing, launching, and warhead variations which are important to actual combat.

- Target damage may be negligible, immediate, or delayed.

- The SS should have general scoring programs with weapon and target characteristics packages added for individual scoring calculations.

- Checks should be made to assess accidental weapon damage to scenario participants which are not directly invovled in a local engagement.

Figure 4-18 is a simplified functional diagram of an instrumentation system designed to score simulated releases/launches of unguided weapons. Note that output locations for the types of scoring results defined in 4.6.3.1 are shown in this figure.

c. Guided Weapons. TESPO has sponsored further study effort through the SETA contractor into the feasibility of simulating the trajectory of self guided weapons in real time as a part of a scoring system for simulated laucnches. This study concentrated on the family of missiles and "smart bombs" that fall into the "launch and leave" category. Examples are the Maverick, Walleye, and Standard Arm. The scoring calculations for such weapons are much more complex than those for unguided weapons since guided weapons respond to complex environmental effects during flight. When jamming energies are added to the guided weapons environment, the simulation problem becomes even more complex.

The framework of the study was based on the following outline:

1) Relative trajectories and orientations of attacker and target (single or group) during the beginning of the engagement.

- Attacker look angles and received jamming power (single or multiple sources).

- Target (single or group) acquisition process with jamming.

- Attacker weapon lock-on problem with jamming.

- Attacker and target identifications to scoring system.

2) Attacker and target trajectories and orientations at weapon launch.

- Weapon Launch perturbations.

- Weapon lock-on problem with jamming.

- Weapon initial trajectory and orientation with respect to target.

# SIMPLIFIED UNGUIDED WEAPON SIMULATION SCHEME

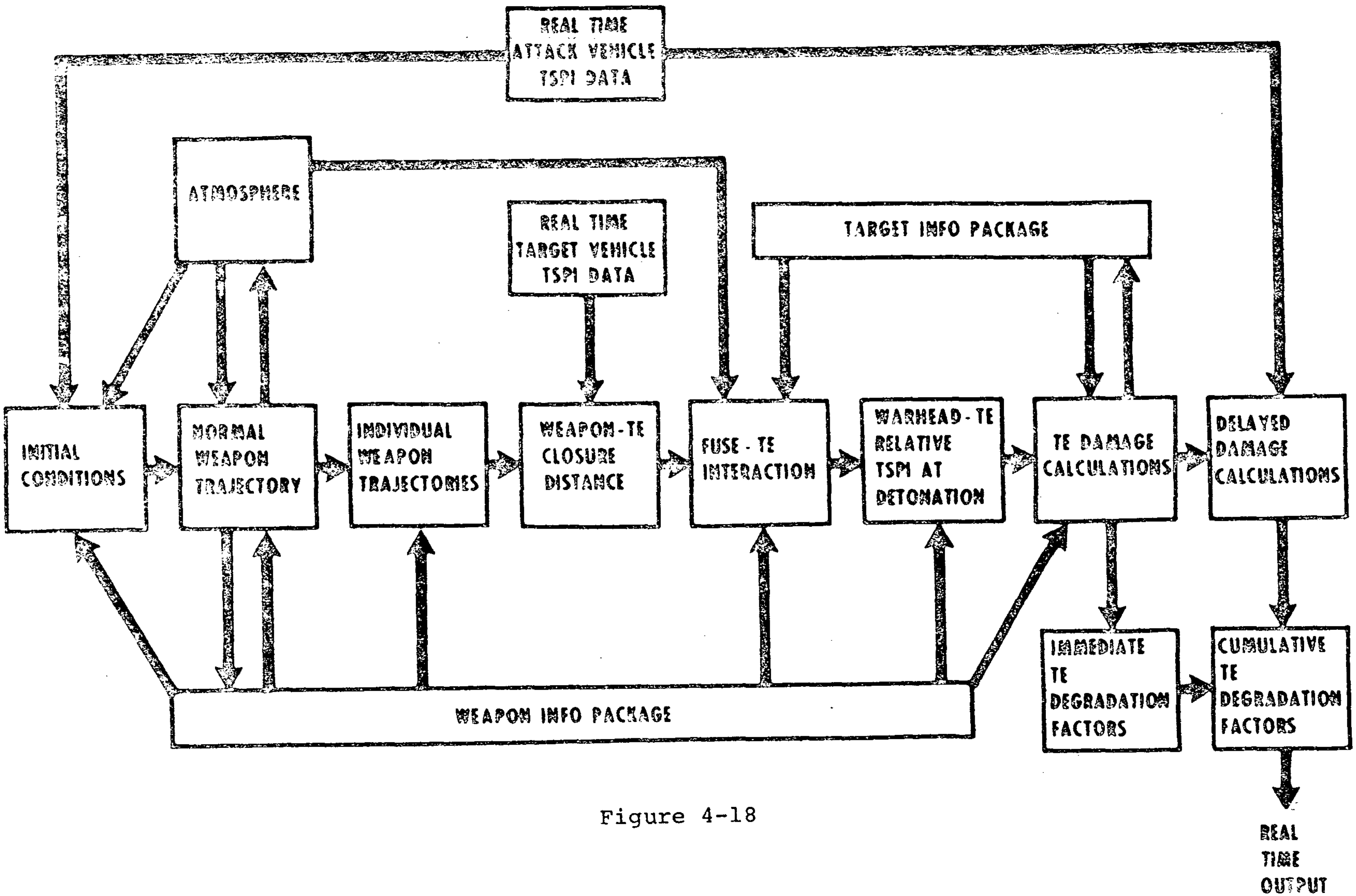



Figure 4-18

3) Weapon guidance with jamming and the resulting trajectory toward target.

- The possibility of acquiring a decoy or a different target in flight.

- Selection of a single target if the weapon was originally aimed at a group.

- Embedded problem: simulation of antimissile missiles or antimissile machine-gun rounds (e.g., U.S.).

4) Terminal Homing Phase.

- Weapon terminal guidance with jamming or nearby radiating objects.

- Weapon fuze operation with jamming or nearby radiating objects.

5) Target Damage Assessment.

- Weapon and target trajectories and orientations at burst.

- Blast and/or fragment effects on a distributed target.

- Weapon penetration of target before burst.

- Possible damage to objects near the target.

The above outline will apply equally to air-to-ground, ground-to-air, and air-to-air self-guided weapons. However, this list of simulation problems is given for one attacker launching one weapon at a single target. It is reasonable to expect a scoring system to be capable of handling multiple, simultaneous launches toward separate targets as well as launches by the targets toward the attackers.

Figure 4-19 is a simplified flow diagram of the general guided-weapon simulation scheme. The output points for the hierarchy of scoring results established earlier are again shown in this figure.

# SIMPLIFIED SELF-GUIDED WEAPON SIMULATION SCHEME

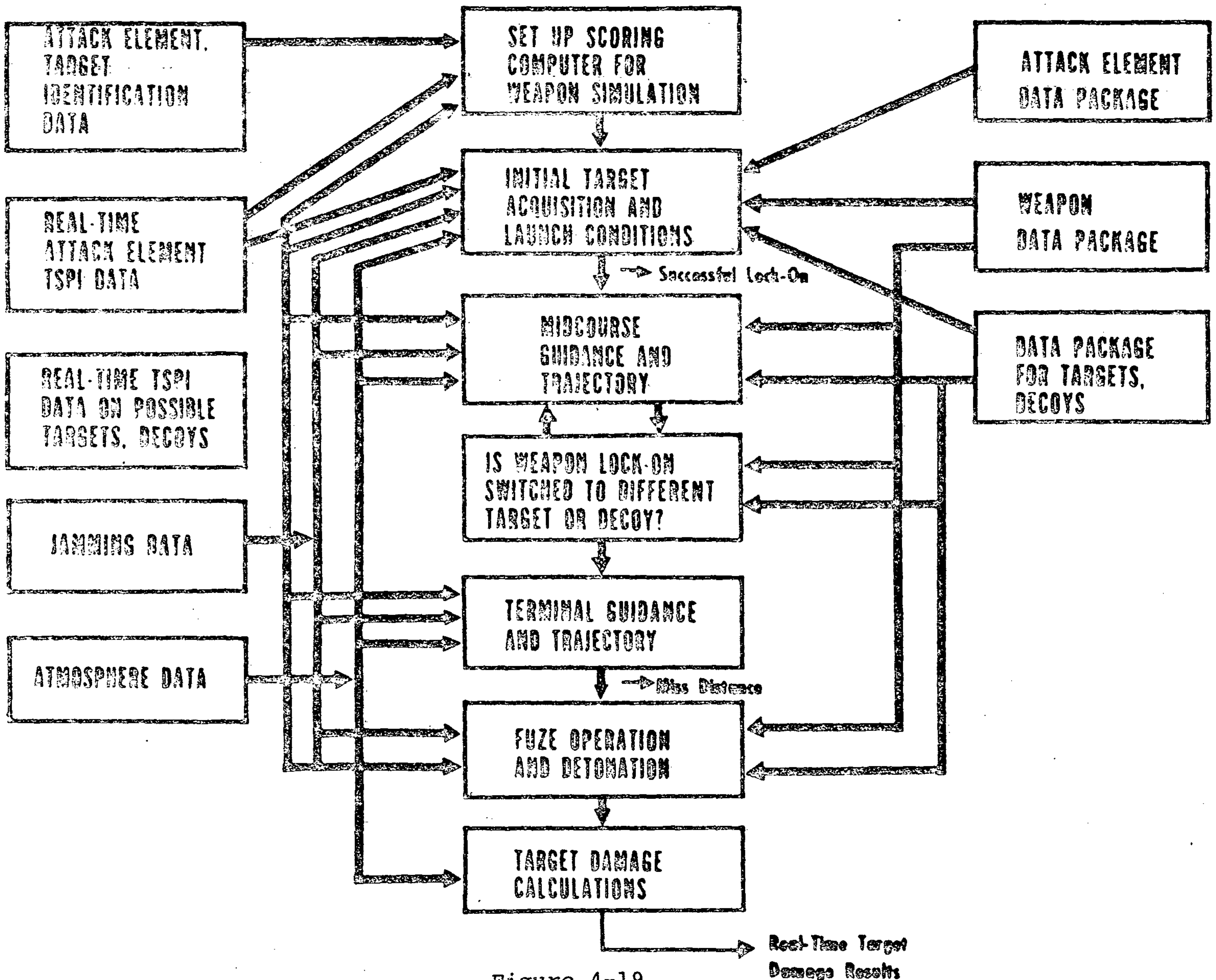



Figure 4-19

d. Results. The results of this study effort can best be summarized by estimating what is required to complete various portions of the simulation effort.

1) Considerable work has been completed on simulations of weapon thrust, aerodynamics, aerodynamic stability, and trajectories. Very little additional effort would be required to incorporate this work into a real time scoring system.

2) The weapon guidance and jamming interactions would require moderate effort to simulate.

3) Target vulnerability, weapon blast, fragmentation effects, and target damage assessment require extensive effort to adequately simulate.

#### 4.6.3.3 Conclusions

a. Unguided Weapons. Tools have been developed to translate accuracy requirements for the miss distance determination of simulated weapons releases to position and flight parameter measurement accuracies of the launch platform. Once the requirement analysis process has established the miss distance requirements, TESPO can specify the instrumentation needed to satisfy these requirements.

b. Self-Guided Weapons. The amount of effort needed to complete a satisfactory simulation of this class of weapons indicates that an envelope scoring approach be used in at least the initial effort to meet the requirements of this segment.

### 4.6.4 Time-Space-Postion Information (TSPI) Systems (Figures 4-20 and 4-21)

In the TT&E improvement program, TSPI requirements may vary considerably between the various ranges/ sites selected for improvement. Therefore, this section addresses the generic categories of TSPI and the techniques available to meet the requirements of each of these categories.

# CANDIDATE TSPI INSTRUMENTATION

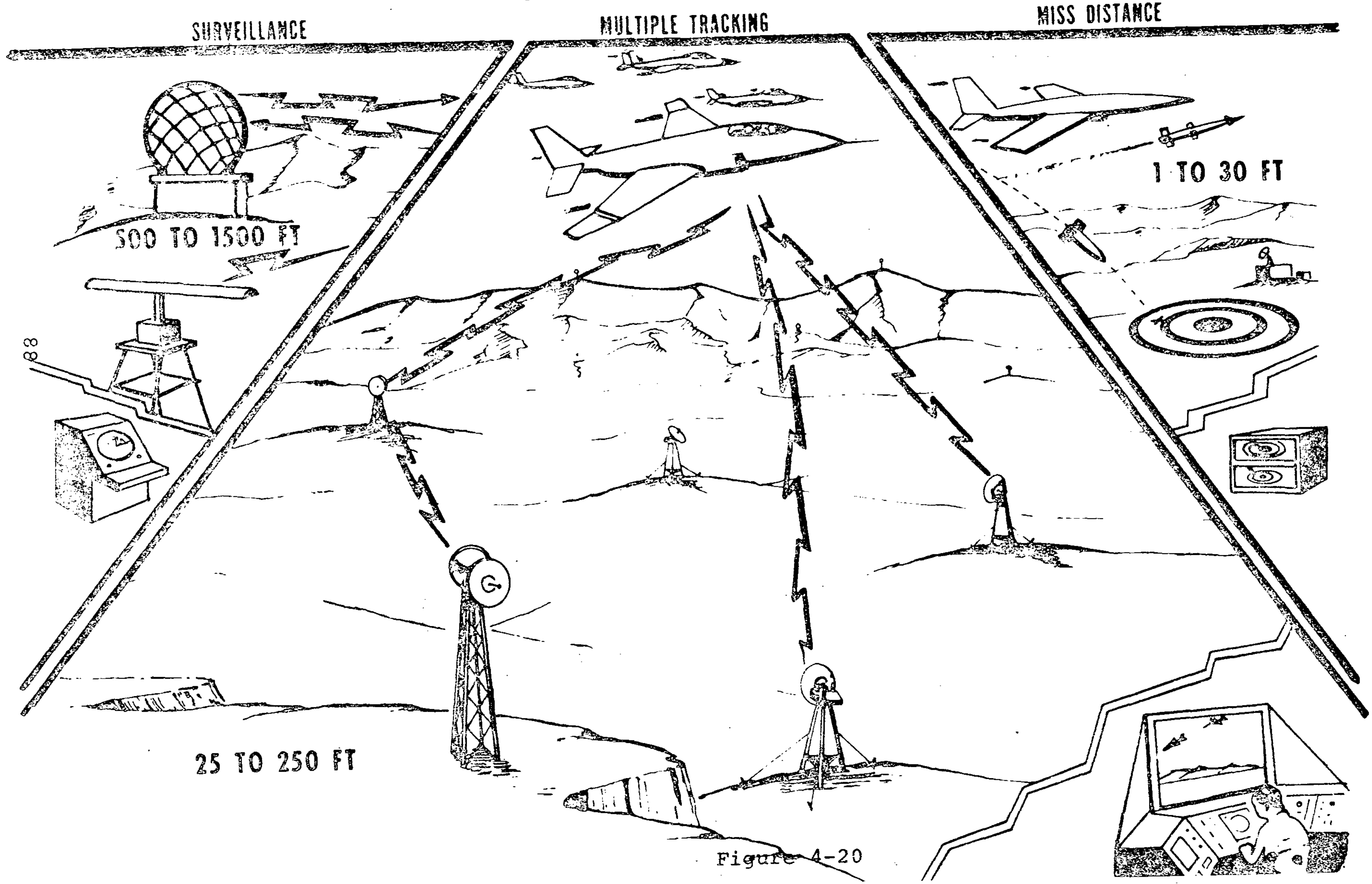



Figure 4-20

# POSITION MEASURING INSTRUMENT SYSTEMS

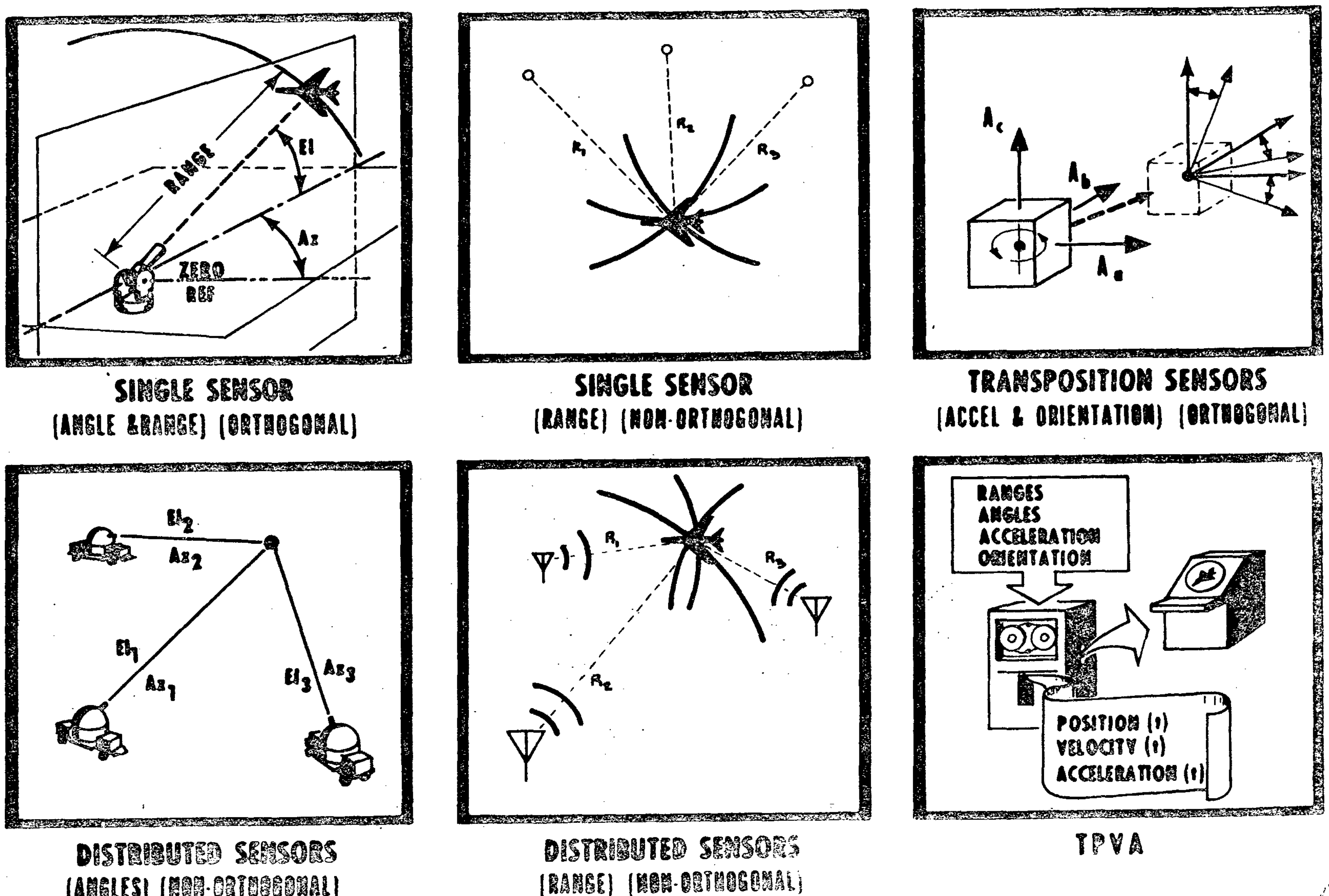



Figure 4-21

#### 4.6.4.1 General

The general requirements for TSPI can be divided into three categories: area surveillance, terminal area TSPI, and TSPI for scoring purposes. The distinction between the first two categories is fairly clear; a requirement exists for air surveillance over a wide area (extending beyond range boundaries) of both cooperative and noncooperative aircraft for purposes of test monitoring, air traffic control, and safety functions. These requirements are characterized by high capacity but relatively low resolution and low accuracy. Within a terminal (attack) area, where high maneuverability and/or formation flying may be expected, a requirement is seen for higher resolution and accuracy on a few aircraft (normally four aircraft simultaneously in a terminal area), which could be expected to be "cooperating" in the particular mission.

The division between terminal-area TSPI and TSPI for scoring is less distinct, and is dependent, to a large degree, upon what is meant by "scoring." A long-term goal of TT&E improvements may be a capability to "score" entire missions or engagements, on the basis of the casualties ("kills") of equipment on both sides--thus generating the requirement for real-time simulation of A/G, G/A, and A/A weapon trajectories, so that "dead" elements could not (unrealistically) continue to influence the final outcome. However, for the next few years at least, some less elaborate technique for scoring multiple-participant encounters may be advisable. Approaches under consideration are: performance measures based on exposure time (such as has been used at Eglin in CORONET ORGAN exercises)--which would draw upon both terminal and wide-area surveillance TSPI sources; weapon "envelope" scoring--for which the terminal area TSPI might be adequate, at least for a large class of self-guided (homing) weapons; and single-target characteristics. This list is not all inclusive, but it does demonstrate the spectrum of techniques available.

a. <u>Surveillance Systems</u>. Area surveillance is required over the entire range, or sometimes even beyond the boundaries of the range, for the purpose of test monitoring, air traffic control, detection of non-participating aircraft which intrude upon an exercise,

or for limiting activities of aircraft to locations designated in the interests of range safety. Surveillance systems are characterized by large coverage volumes, modest accuracy requirements and the necessity for handling large numbers of aircraft simultaneously. For the wide-area surveillance function, an obvious candidate is the currently existing FAA network of primary and IFF/ SIF radars, exploiting the ATCRBS transponders already aboard virtually all military and commercial civilian aircraft. Augmentation of FAA coverage in any range area by the addition of Air Force search or surveillance radars and IFF interrogators may be necessary, particularly at low altitudes and on aircraft not equipped with ATCRBS transponder. Other candidates may require similar interaction of existing systems.

b. Terminal Area. The terminal area is that in which engagements between aircraft-and-aircraft or aircraft-and-ground targets or various combinations of these events take place. A surveillance system depends upon aircraft flying a regularly ordered course in response to ground direction and thus can relax accuracy and sampling time requirements because the aircraft path is predictable. In constrast, in the terminal area, simulation of combat events results in frequent unpredictable maneuvers and consequently considerably increased accuracy over that required for surveillance systems is needed. On the other hand, the coverage volume of such systems is much less than for surveillance systems and the number of simultaneous participants is much smaller. Multilateration techniques offer the most promise for terminal-area TSPI of medium accuracy (on the order of 50 ft RMS error). Several proven and operational systems are available, all of which involve the use of a cooperative transponder carried in a weapon-shape pod by the participating aircraft. These include the Cubic ACMR, the General Dynamics RMS, and the IBM ALSS. As another alternative for low-density situations, exploitation of IFF/SIF multilateration technique such as proposed in the Sierra Research HAILS (High Accuracy Instrumentation and Location System) proposal has merit, as a medium-accuracy terminal TSPI system which would require no aircraft pods.

c. Scoring Systems. Scoring systems measure the effectiveness of a weapon directed against a target. The situation may be air-to-air (aircraft engaged in a dog fight and firing weapons at each other), air-to-ground (bombing, strafing, firing of ARMs, etc.), ground-to-air (SAM missiles) or ground-to-ground (artillery). The distinction between terminal TSPI and scoring systems is somewhat blurred, since terminal systems are used for evaluation of the engagement and thus represent "scoring" of the exercise. Scoring systems are usually associated with real or simulated one-on-one engagements where high accuracy is required to determine miss-distance, probability of kill, or entrance into a kill envelope. Less accurate, wider range systems are placed in the terminal TSPI category.

4.6.4.2 Measurement Systems

a. Single Point System. Single point position measuring systems make use of a single measurement station in which the position of a target is determined by measuring range to the target and azimuth or azimuth and elevation angles. Single point systems typically consist of radar or laser system since only these systems permit range measurement. Single point systems which measure both azimuth and elevation angle can consist either of a single radar or of separate azimuth and height finding radars.

b. Distributed Sensor Systems. Distributed sensor systems consist of two or more measurement sensors located some distance from each other. Each sensor makes a measurement of target angle and/or range and then a mathematical computation is used to extract target position.

4.6.4.3 Range Measurement Techniques

a. Pulse Ranging Techniques. A pulse of energy is transmitted which is reflected from the target. Measurement can be made by use of the leading or trailing edges of the pulse or a derived centroid.

b. CW or Phase Comparison Ranging. Range information is extracted from the reflected signal by measuring the phase difference between transmitted and reflected waveforms.

c. Doppler Effect Range Measurement. Moving targets disturb the reflected waveform in time and change the frequency of the transmitted signal by a doppler frequency proportional to velocity. Use of this doppler frequency can be made to obtain target velocity and ranging.

4.6.4.4 Angle Measurement Techniques

a. Mechanical Angle Measurement. The most common technique for obtaining angle measurements is to determine the axis of the tracking system, point the axis at the target to be measured, and then measure the angles between the axis and reference coordinates.

b. Interferometry Angle Measurement. Use is made of several antennas along a common baseline and measuring the phase difference in signals arriving at each antenna.

c. Monopulse Tracking. Monopulse tracking involves the use of offset beams whose signal returns are combined to produce the sum and difference signals which are multiplied together to produce an error output which is used to precisely reposition the antenna mount. Angle encoders on the antenna are then used for angle measurement.

d. Phased Array. By mounting a number of dipole antennas in a properly spaced array, a composite pattern resulting from the summed contributions of all of the dipoles can be generated which is dependent upon relative signal phase. The result is a narrow signal beam which can be used for tracking. Computation of relative element signal phases can be used to determine angle measurement.

e. Multilateration. Three stations, measuring slant range to a target, are sufficient to establish target coordinates. In practice more stations are arranged in the system grouping, and computation is performed to determine and use stations giving best angular position (ideally at the apexes of an equilateral triangle). For non-radar trilateration, a cooperative target transponder is required to determine transit time and derived slant range.

f. Time Difference of Arrival. A receiver is used to pick up signals from a pair of stations whose positions with relation to each other are known. The receiver measures the difference between the time of arrival of the signals and from the two stations which is a measure of the difference in range from the receiver to the two stations. Additional stations (minimum of four total) are used for computation of three dimensional position.

4.6.4.5 Equipment Listing

Detailed descriptions of TSPI systems and associated considerations are contained in 2FTP - H0386005, "Survey and Information for Selection of Time-Space-Position Information Systems for USAF OTT&E," AFSWC/TE, Kirtland AFB, New Mexico, June 1975. A partial equipment matrix, extracted from that document is included on Table 4.2.

4.6.4.6 Conclusion

A TSPI study is being published as a separate volume entitled, "Survey and Information for Selection of TSPI for USAF Operational Training, Testing and Evaluation (OTT&E)," 2FTP - H0386005. The first portion of this volume presents 75 TSPI systems which are currently conceptual, developmental, or operational stages. These systems are a representative cross section of all major techniques for obtaining Time-Space-Postion Information. The report provides a brief description each system, descriptions of the basic operating principle for each system and discussions of the various problems and sources of error which may be encountered. This first portion of the volume is meant to serve as a basic reference document for selecting TSPI systems for individual TT&E improvement projects.

The second portion of the volume determines TSPI requirements for fifteen generalized missions that form a cross-section of OTT&E activities of the Air Force over the next ten years. Matrices are provided to demonstrate how particular TSPI systems are applicable to particular mission test requirements. This survey provides a basis for developing the performance specifications for obtaining the necessary TSPI system, whether through improvement of existing, on-range equipment, procurement of a system, or further improvement of TSPI system technology.

## TSPI CANDIDATES

| SYSTEM | STATUS | COVERAGE AREA (RADIUS) (N.M.I.) | COVERAGE MIN. ALT. | TRACK CAPACITY Lo Rate/Hi Rate | ACCY (X,Y)/Z OR R/(A,E) | RESO. | ATT. DATA | A/C EQUIP REQUIRED | REAL TIME DATA PROC. & DISPLAY |
|---|---|---|---|---|---|---|---|---|---|
| IFF<br>HAIL | Final Engineering | 25 Mi. | LOS | 20/4 | 40'/100' | Garble Lim. | N | ATCRBS | Y |
| MULTILATERATION<br>RMS/SCORE<br>ALSS | Final Test<br>Operational | 20-40<br>100 | To Gnd.<br>To Gnd. | 1023/30<br>127/12 | 10'/45'<br>10'/- | Indiv A/C<br>" | 2°<br>N | POD Transponder | Y |
| TRACKING RADAR<br>PAIR** | Concept | 75 | LOS (1°) | 200 | 1'/0.06mr | A/C in formation (2 fps) | N | N (Beacon) | Y |
| ON-AXIS RADAR<br>TORIS | Concept | 127 | LOS (1°) | 1 | 3'/0.03mr | | N | N (Beacon) | Y |
| LASER TRACKER<br>PATS | Operational | 16 | LOS | 1 | 5'/0.3mr | | N | Retro-reflector | Y |
| OPTICS<br>RTCDS | Operational | 4 | To Gnd. | 1 | 3'/3' | A/C Dimen. | R/Post Msn | N | Y |
| AIRBORNE<br>AWSS* (CRSS)** | Concept | 125-250 | To Gnd. | 60-100 | 30'/2.5mr<br>30'/2.5mr | Indiv Aircraft | Y | POD | Y |
| NAVIGATION<br>LORAN/INERTIAL** | Hardware Developed | 125-250 | To Gnd. | Unlim.<br>80 | 80'/100' | Indiv Aircraft | 1°-2° | POD | D.P. |
| SATELLITE<br>GPS** | Under Development | Global | To Gnd. | Unlim. | 24'/29' | Indiv Aircraft | N | Rcvr/Processor | D.P. |

*Relative position and altitude measurement.
**Not available until after 1978.

TABLE 4.2

### 4.6.5 ACMI (Figure 4-22)

#### 4.6.5.1 Background

The initial ACMI requirement is for the capability to monitor and score air-to-air combat training. The ACMI must be capable of identifying and tracking a specified number of participants; determine attitude, position, absolute and relative velocities; record firing actions and hit or miss distances for inventory aircraft-weapon combinations; display activity in real-time for safety, control and optimization of training; and record parameters for a full playback presentation. This system must perform these functions with minimum modifications to aircraft.

#### 4.6.5.2 Current ACMI Status

Equipment is presently in operation which is capable of such performance. Acquisition of ACMI capable of air-to-air training functions must be viewed in conjunction with the future requirements for precise weapon scoring to permit the use of the "building-block" acquisition scheme.

The ACMI system to be procured for the Nellis Range is based upon previous Navy development and follows the concept of equipment commonality. Ground stations are remoted and require minimum personnel support while the airborne instrumentation pod is to be designed for "blue suit" operation and maintenance. Centralized procurement of this initial AF system in conjunction with the U.S. Navy will insure compatibility between DOD users and allow multi-service use of such systems.

The initial Nellis system will cover a 30 to 40 NM diameter vertical cylinder of airspace with the capability of diameter expansion by the addition of more ground stations. The feasibility of integration of ACMI with TSPI will require study based upon range user identified requirements.

# AIR COMBAT MANEUVERING INSTRUMENTATION

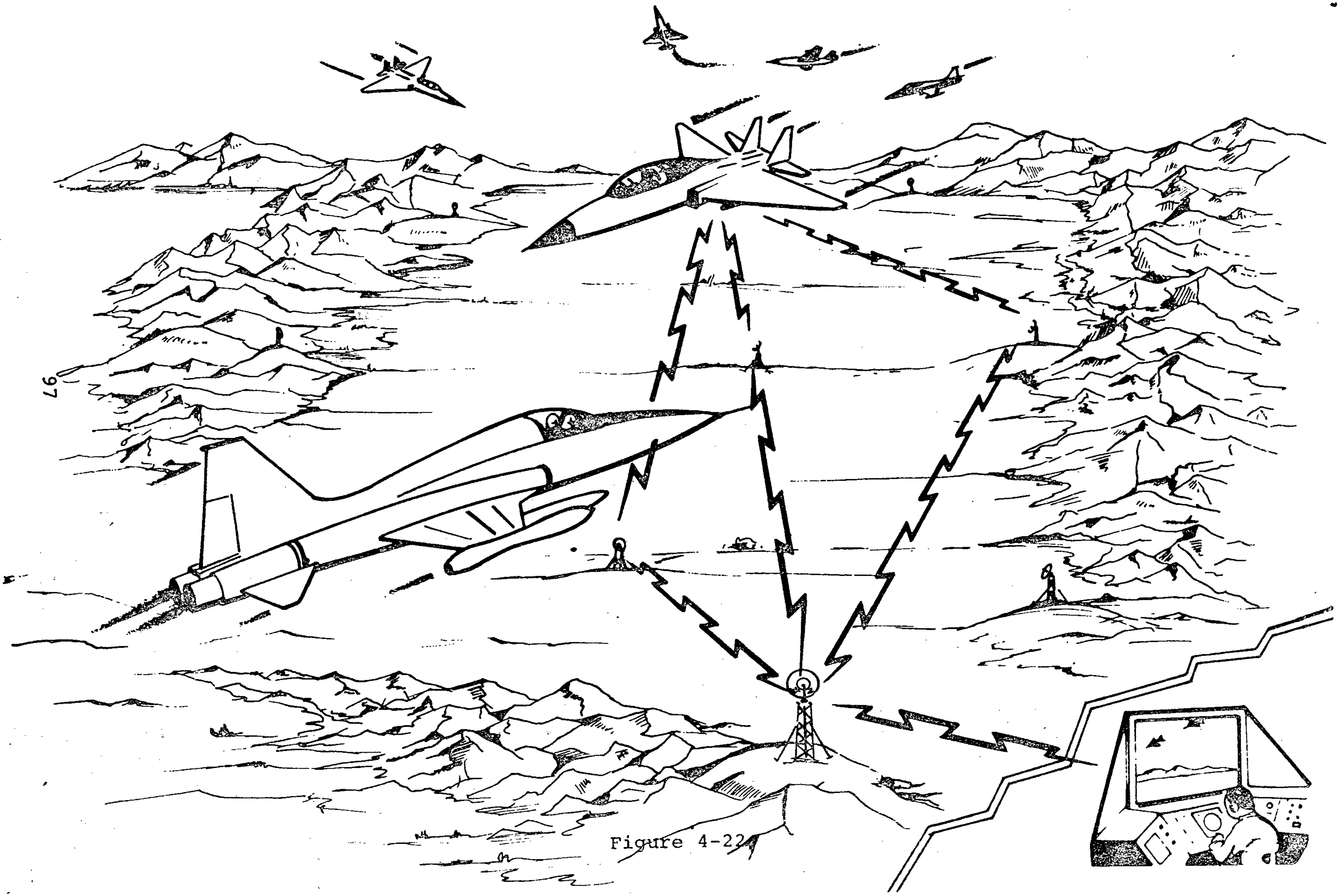


Figure 4-22

4.6.6 Ordnance Scoring. (Figures 4-23, 4-24 and 4-25)

The goal of this segment is to discuss the scoring of real weapons, inert and live, and to suggest suitable scoring systems from among those presently available. Air-to-air, air-to-ground, and ground-to-air weapons will all be considered.

4.6.6.1 General

Scoring of real munitions can be based on cooperative or non-cooperative systems. Cooperative systems require that some device (refelctor, beacon, telemetry transmitter, etc.) be installed on the weapon being scored. Non-cooperative systems do not require an on-board tracking aid. For actual launches (or drops), a non-cooperative scoring system is desirable. Factors against cooperative systems are the destruction of any on-weapon instrumentation, the difficulties in instrumenting some weapons (MG, cannon, small rockets), and the use of small practice bombs to simulate actual bombs. Cooperative systems can be put on guided missiles, guided bombs, and the larger unguided weapons; however, this would constitute modification of the operational system, loss of the instrumentation with each launch test, and could reduce realism.

Of the four scoring techniques discussed in 4.6.3.1, miss-distance scoring, kill-no kill scoring, and damage-assessment scoring are appropriate for real weapons. Miss-distance scoring especially applies to real, live weapons; e.g., live cannon rounds missing an airborne target. For real, live weapons, damage-assessment scoring is most appropriate if the target damage can be inspected after weapons firings are determined. Kill-no kill scoring then becomes two special cases under damage-assessment scoring. If, however, the target is not available for post-shot inspection, arbitrary rules will be required to impose kill-no kill scoring on the effects of real, live weapons. Missile effectivness against an aerial drone flying over water, for example, might simply be decided: "kill" if the drone is falling out of control within ten seconds of missile detonation, "no-kill" otherwise.

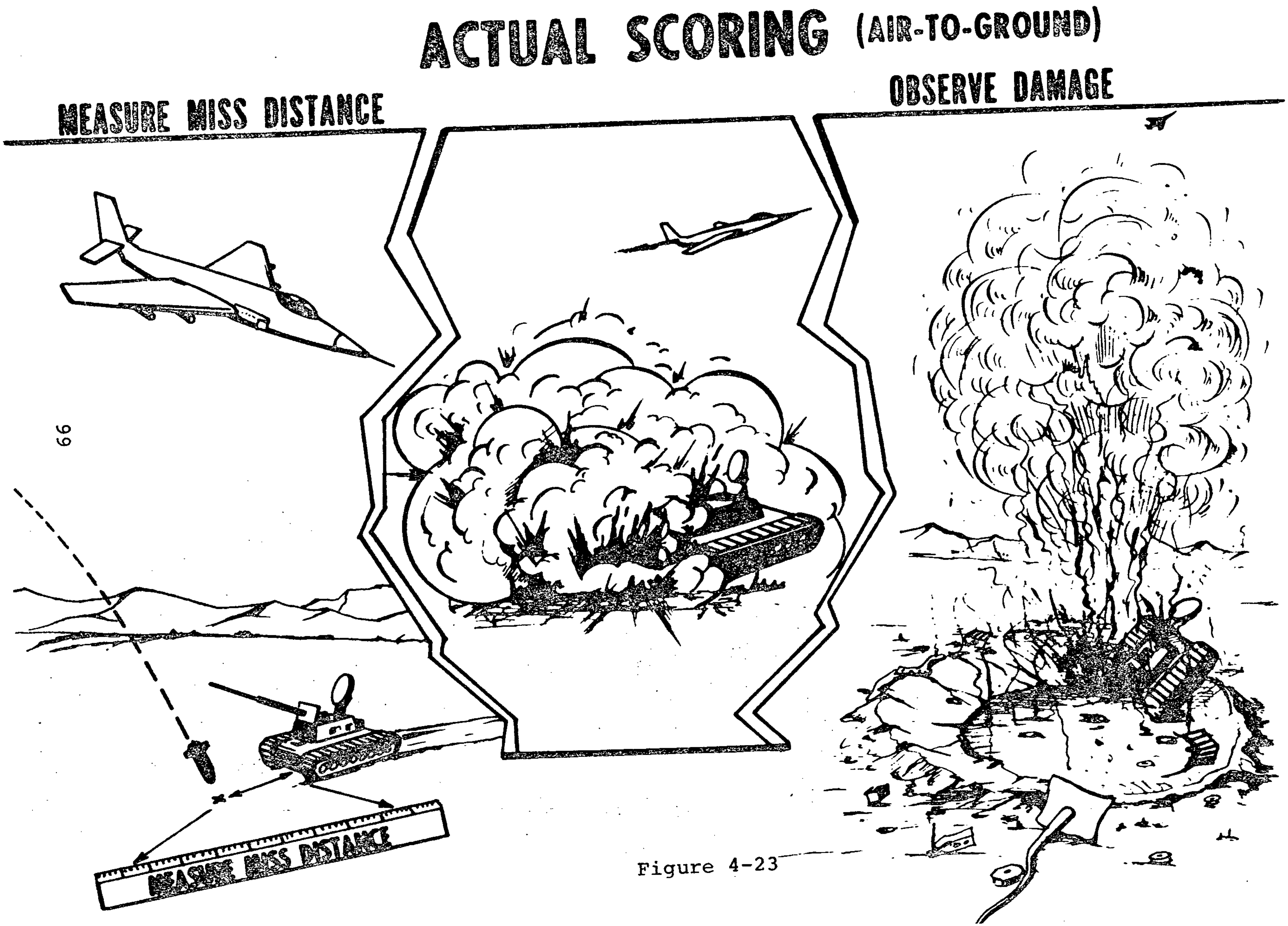

ACTUAL SCORING (AIR-TO-GROUND)
MEASURE MISS DISTANCE
OBSERVE DAMAGE
MEASURE MISS DISTANCE

Figure 4-23

# ACTUAL SCORING
## (AIR-TO-AIR)

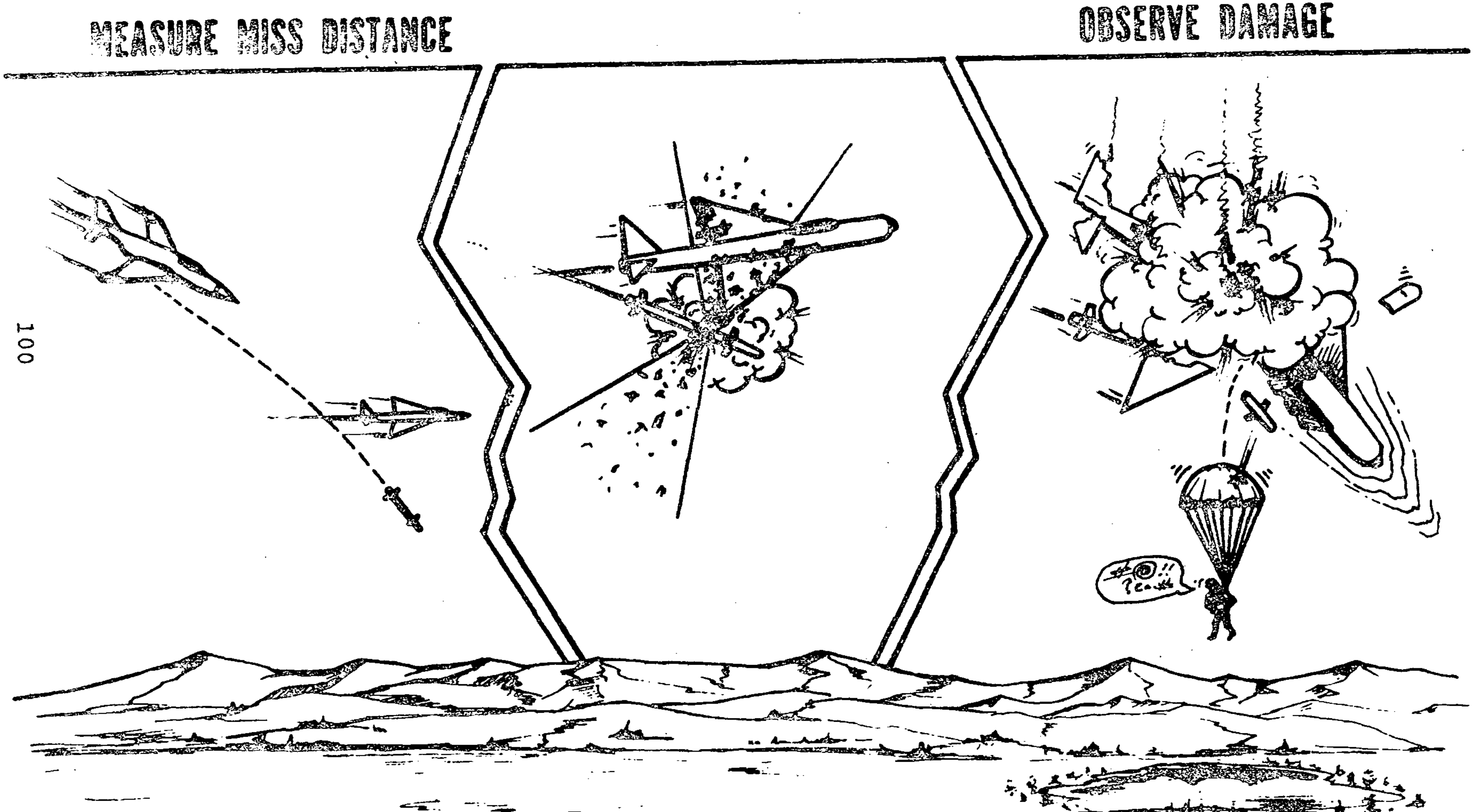



Figure 4-24

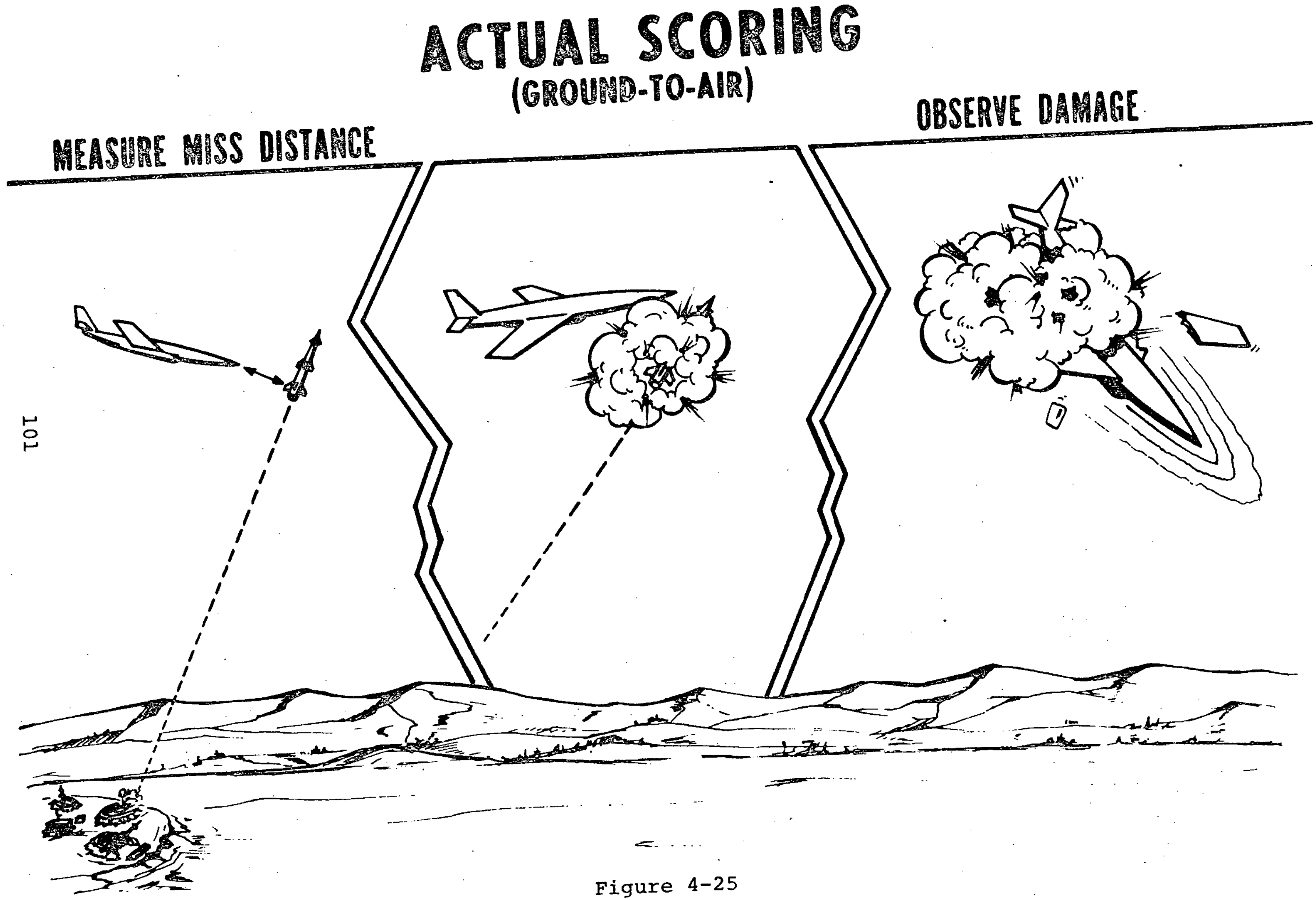

ACTUAL SCORING
(GROUND-TO-AIR)
MEASURE MISS DISTANCE
OBSERVE DAMAGE

Figure 4-25

#### 4.6.6.2 Technical Principles Used to Score Real Ordnance

A companion document, 2FTP - H0386005, "Survey and Information for Selection of TSPI for USAF Operational Training, Testing and Evaluation (OTT&E)," discusses in detail the engineering principles used in existing scoring systems for real ordnance applications. The most successful of these principles are sketched briefly here:

a. Radio Frequency (RF). Microwave and radar systems are used for miss distance or impact scoring by trajectory tracking. The accuracies and relatively short effective ranges of these devices dictate the use of scoring systems specifically developed for this purpose. These are non-cooperative systems in most cases in which bomb and missile live deliveries are evaluated.

b. Optical. Video and film recording have been used for real launches. Some systems use video techniques for scoring bombs, rockets, and larger guns (e.g., Celesco LAROSS). In some cases, near real-time evaluations are possible. Post-flight analysis of both video and film recordings is most common. These systems provide an automated means to count and survey the deliveries. A permanent recording is obtained and fine-grained analysis is possible. Film processing, play-back equipment, software, and film storage are drawbacks to these systems. Machine gun and cannon fire cannot be scored with these systems unless a dirt or water splash is used; however, this technique does not provide the accuracy needed.

c. Lasers. Scoring bombs, missiles, and other weapons by laser techniques are essentially identical in principle to RF scoring systems except that some reflection cooperation between the weapon and scoring device may be required. Laser techniques offer the advantages of no RF emissions and greater accuracy than comparable RF techniques.

d. Acoustic. Acoustic systems rely on the sound of impact or burst. Variations in the speed of sound, other sound generators such as the aircraft, and rate of delivery (MG and cannon) are primary problems in use of these systems.

e. Seismic. As the weapon impacts the ground, seismic waves are generated. Scoring is accomplished by timing the signal arrival at a number of surveyed sensors. Aircraft noise, multiple concurrent deliveries, inconsistencies in terrain, and calibration problems, all tend to eliminate these systems as candidates.

#### 4.6.6.3 Survey of Some Existing Systems for Scoring Real Weapons

Each TSPI-like and scoring system described in 2FTP - H0386005 has been reviewed. Systems designed to score simulated weapons deliveries have been eliminated, as have surveillance and terminal TSPI systems. Finally, real-weapon scoring systems which do not give results in (near) real time were omitted. The reduced list, containing only near-real-time systems for scoring real weapons deliveries, inert or live, is given here as Table 4.3. These scoring systems have ben further categorized according to their possible application to Air-to-Ground, Air-to-Air, and/or Ground-to-Air weapons deliveries. (Table 4.4.)

#### 4.6.6.4 Comment and Conclusions

Inspection of Tables 4.3 and 4.4 shows that no one scoring system will be suitable for real guns and rockets, missiles, and bombs in Air-to-Ground, Air-to-Air, and Ground-to-Air scenarios. The variety of scoring requirements determines that multiple procurements will be necessary to synthesize an all-weapon, all-scenario scoring system for real ordnance.

Neither the accumulation of TSPI-like and scoring systems in 2FTP - H0386005 nor the abbreviated list is exhaustive. Further, new scoring systems are being developed and proven each year. Even the person who wishes to test one type of weapon in one type of scenario should, therefore, regard the information herein as an aid, and he should investigate other potential scoring systems.

TABLE 4.3: NEAR-REAL-TIME SCORING SYSTEMS FOR REAL WEAPONS

(Reference [a])

| Paragraph in Ref. [a] | Scoring System | Page in Ref. [a] | System Applications |
|---|---|---|---|
| 5.5.7 | AN/FPS-16 Precision Tracking Radar | 59 | Track one real a/c, missile, or bomb |
| 5.5.10 | Phased Array Instrumentation Radar (PAIR) | 61 | Track 100-200 a/c, missiles, or bombs |
| 5.5.14 | Cooperative Doppler Scoring System (CODOPS) | 65 | Coarse miss distance for one a/a missile passing drone |
| 5.5.15 | Digidops Scoring System | 66 | Miss distance for one a/a missile passing drone |
| 5.5.16 | Miss-Distance Indicator Systems | 67 | Fine miss distance for one a/a missile passing drone |
| 5.5.18 | Vector Miss Distance Indicator (VMDI) | 72 | Miss distance, fuze data, velocities, angles, calculated kill probability for missile passing drones |
| 5.5.19 | Miss Distance Radar Tracking and Scoring System (MIDI) | 73 | Miss distances of cannon rounds passing airborne target |
| 5.5.20 | Octant and Zone Gunnery Scoring System | 74 | Miss distances and octant locations of cannon rounds passing airborne target |
| 5.6.1 | Bidops Electronic Scoring System | 77 | Miss distance for one a/a missile passing drone |
| 5.7.1 | Precision Automated Tracking System (PATS) | 77 | Track one real a/c, missile, or bomb |
| 5.7.2 | Laser Vector Miss Distance Indicator (VMDI) | 78 | Miss distance, relative velocity of one weapon air or ground target |
| 5.9.1 | Acoustiscore | 85 | Scores impact, locations of MG, cannon rounds in a/g strafing of instrumented target |

TABLE 4.3: NEAR-REAL-TIME SCORING SYSTEMS FOR REAL WEAPONS (Cont.)

(Reference )

| Paragraph in Ref. | Scoring System | Page in Ref. | System Applications |
|---|---|---|---|
| 6.3.1 | Multiple Airborne Target Trajectory System (MATTS) | 90 | Tracks cooperative interceptor, missile, target to provide vector miss distance missile passing target |
| 6.3.5 | Real Time Cinetheodolite Data System (RTCDS) | 95 | Computer-smoothed tracking data on one air vehicle |
| 6.3.8 | K 400 Cinetheodolite and Tracking System | 98 | Tracks one real a/c, missile, or bomb |
| 6.3.9 | Light Attack Range Optical Scoring System (LAROSS) | 98 | TV-computer system for scoring impact points of real, inert bombs |
| 6.3.10 | Video Bomb Scoring | 99 | TV-computer system for scoring impact points of real, inert bombs |
| 6.5.10 | Automatic Scoring System | 128 | Scores ground impact points of real air-delivered weapons |
| 7.2.8 | Point of Impact Scoring System (POI) | 174 | Impact point scoring of real, live a/g and g/g projectiles |

| Air-to-Ground Weapons Deliveries | Air-to-Air Weapons Deliveries | Ground-to-Air Weapons Deliveries |
|---|---|---|
| 5.5.7 | 5.5.7 | 5.5.10 |
| 5.5.10 | 5.5.10 | 5.5.19 |
| 5.5.14 | 5.7.2 | 5.5.20 |
| 5.5.15 | 5.9.1 | |
| 5.5.16 | 6.3.8 | |
| 5.5.18 | 6.3.9 | |
| 5.5.19 | 6.3.10 | |
| 5.5.20 | 6.5.10 | |
| 5.6.1 | 7.2.8 | |
| 5.7.1 | | |
| 5.7.2 | | |
| 6.3.1 | | |
| 6.3.5 | | |
| 6.3.8 | | |

TABLE 4-4: 2FTP - H0386005 REFERENCES TO WEAPONS-DELIVERY APPLICATIONS OF SOME EXISTING SCORING SYSTEMS FOR REAL WEAPONS (INERT OR LIVE)

4.6.7 Airborne Instrumentation. (Figure 4-26)

TESPO has sponsored a study effort through the SETA contractor into the feasibility of generating a common data point in tactical aircraft. This study would address the design of such a capability in new aircraft and its inclusion in an avionics up-date program.

This study will be considering, as examples, the following aircraft: F-16, F-15, A-10, F-5 and EF-111.

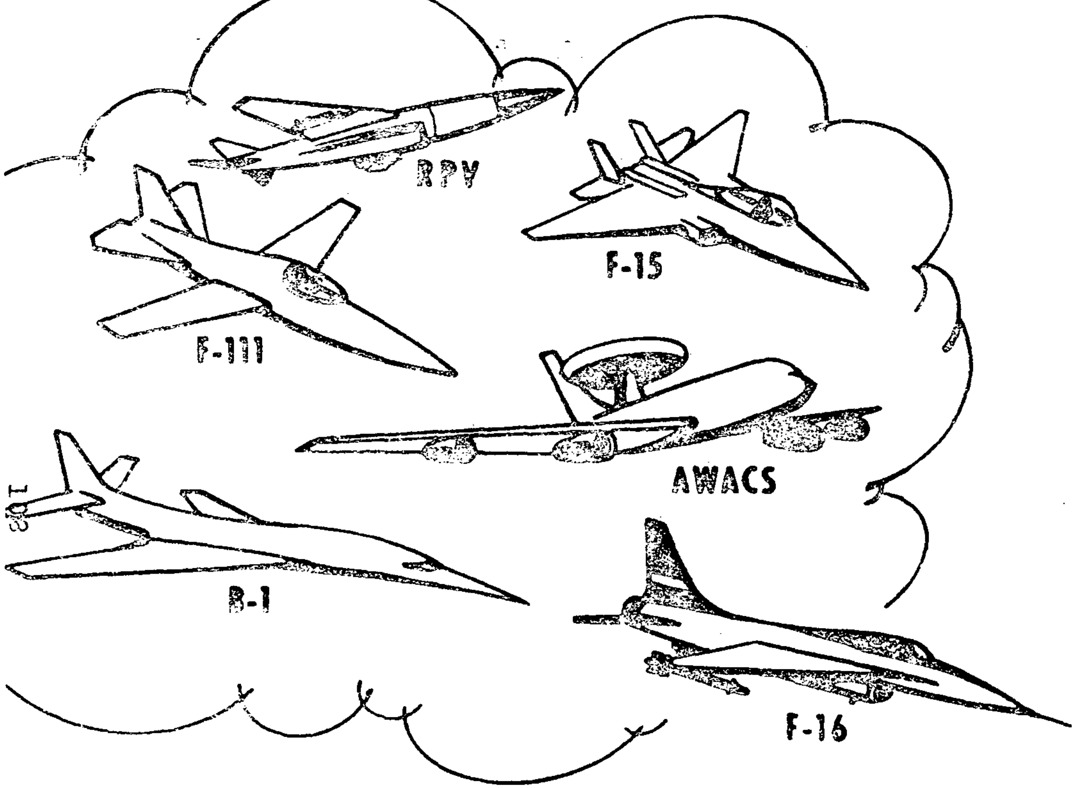
The establishment of a common data point in tactical aircraft would permit the collection of critical information from on-board instrumentation. Such a capability for extracting this data would eliminate the requirement to generate many of the same types of information with "add-on" instrumentation pods. Such information would be valuable in training and tactics development and monitoring and diagnosing situations which arise in combat.

4.6.7.1 Standard Airborne Instrumentation System (SAIS). (Figure 4-27)

Development of a "Standard Airborne Instrumentation System (SAIS)" will follow as a natural consequence of ACMI procurement. The SAIS pod approach would be an interim solution until new or modified aircraft are available that could provide the desired information from a "common data point." The existence of such a data point would allow the time division multiplexing of the already formated data to a down link or an on-board recorder. The SAIS or the concept of a common data point will reduce the number of required instrumentation pods.

a. As a minimum, the SAIS will be designed to operate with RMS-2/score, APX-95, and ACMI type ground systems. The SAIS will provide highly accurate, real-time data to support OTT&E scoring of ground-to-air, air-to-air, and air-to-ground operations. The data to be provided will consist of:

# AIRBORNE INSTRUMENTATION




## INFORMATION

- WEAPON SWITCHOLOGY
- ALTITUDE
- ATTITUDE
- TIME
- POSITION
- VELOCITY
- ACCELERATION

## MAJORITY CASES

- DON'T GET IT
- APPROXIMATE
- MANUAL

## BETTER SOLUTION

- WEAPON BUS
- AIR/NAV DATA
- IFF OR COMM
- ADD WIRING

## SOME USE PODS

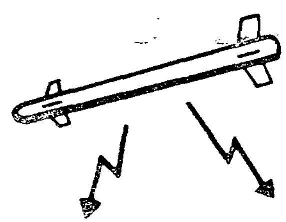


Figure 4-26

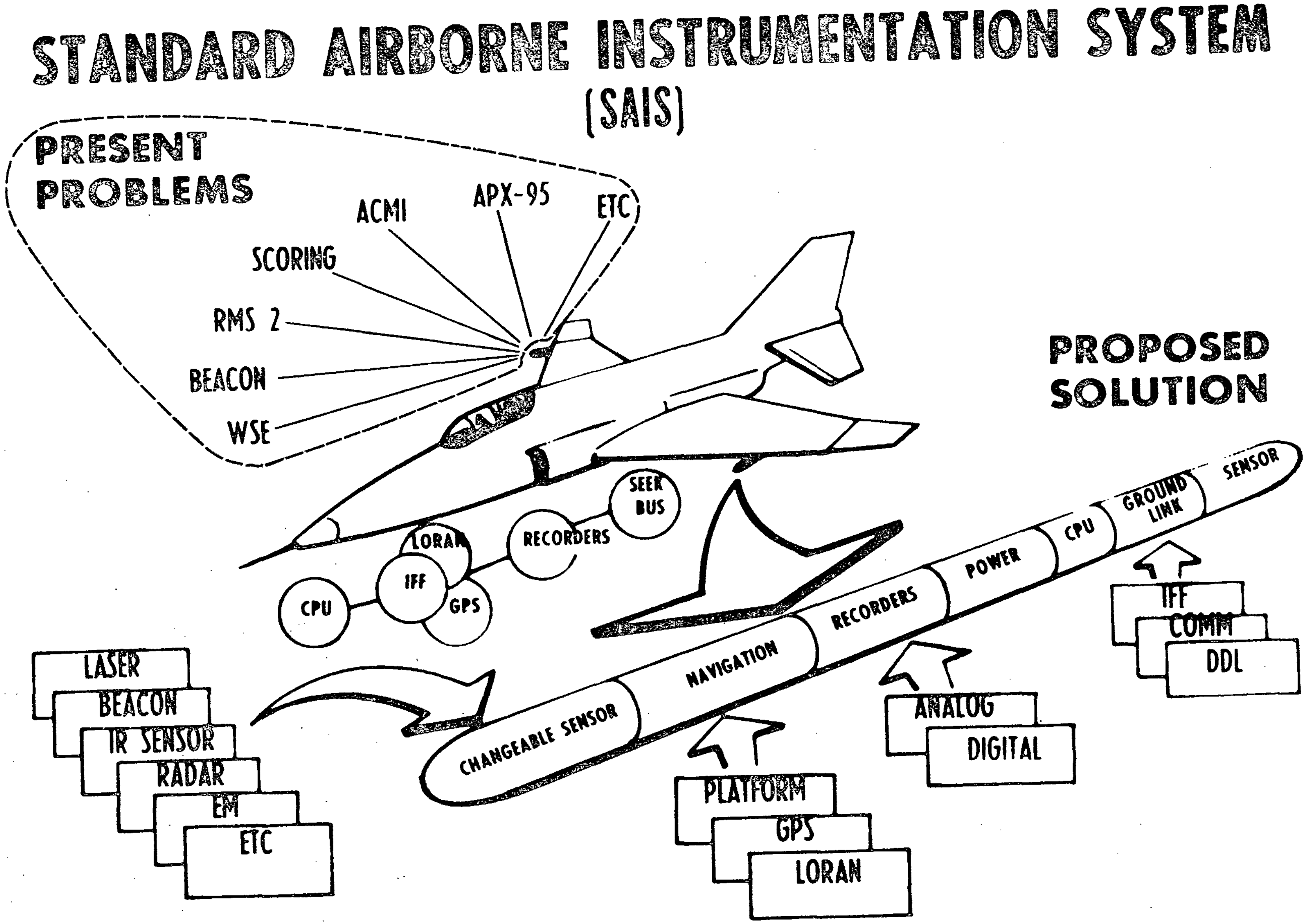

STANDARD AIRBORNE INSTRUMENTATION SYSTEM
(SAIS)
PRESENT PROBLEMS
ACMI
APX-95
ETC
SCORING
RMS 2
BEACON
WSE
SEEK BUS
RECORDERS
LORAN
IFF
GPS
CPU
PROPOSED SOLUTION
CHANGEABLE SENSOR
NAVIGATION
RECORDERS
POWER
CPU
GROUND LINK
SENSOR
LASER
BEACON
IR SENSOR
RADAR
EM
ETC
PLATFORM
GPS
LORAN
ANALOG
DIGITAL
IFF
COMM
DDL

Figure 4-27

- Aircraft attitude and dynamics.

- Missile and fire control system parameters from each selected weapons station.

- Visual indication of a "kill;" i.e., smoke.

b. An on-board digital recorder is used to store the data as it is formated and time tagged by the processor. A down link is also available to transmit the data for ground display as in a test/ training situation. The interchangeable instrumentation feature of SAIS will allow for installation of such systems as AGM-65, SRAM, and the Pave Strike weapons.

#### 4.6.7.2 Utilization of Internal Aircraft Instrumentation

In any consideration of the need "to improve Air Force capabilities for Operational Test and Evaluation (OT&E) and Training" it is natural to think immediately of the several test ranges where the Air Force conducts most of its OT&E and training, and to visualize those patches of real estate dotted with more and better paraphernalia for measurement and data collection; i.e., tracking devices, telemetry stations, communications equipment, computers, displays, etc. These items are of course necessary, and increasing the quality and quantity of such equipment obviously enhances the ability of the Air Force to perform its test and training functions. However, in the preoccupation with the challenging problem of accurate trajectory measurement (particularly for aircraft) and the equipment needed for its rapid transmission, processing and display, another area for high-payoff investment in improved capability may have been overlooked--namely, the incorporation of technical means to facilitate testing and training into the aircraft themselves, which are the subject of operational testing or training, or at least, the vehicles within which Air Force systems to be tested are often embedded.

##### 4.6.7.2.1 Cooperative Instrumentation

Indeed, even with the best of ground-based instrumentation, test ranges usually demand or expect some

kind of electronic "cooperation" from aircraft (or missiles) under test. This cooperation often takes the form of a transponder which assists the ground equipment in measuring ranges or angles, and may also serve as a data-link (one-way or both directions) between the air vehicle and the ground. The reasons are largely economic: the use of a cooperative transponder affords options for TSPI systems which would otherwise be impossible, or at least much more expensive. Transponders are used with tracking radars even when they are (theoretically) unnecessary, to "clean up" the tracking by mitigating or removing such problems as glint, scintillation, multipath, and ground clutter. For surveillance, IFF/ATCRBS may be employed to "enhance" search radar, and to serve as a (limited capacity) data link from air to ground.

In addition to the need for electronic cooperation for trajectory measurement, there are some categories of information which are simply more easily obtained from instrumentation carried by the aircraft than by instruments on the ground. Attitudes and rates of change of attitude, for example, are more easily measured by inertial sensing elements carried by the air vehicle. Also, the direct measurement of acceleration by airborne accelerometers has a better chance of being accurate (and up-to-date) than an inferred value obtained by doubly-differentiating (perhaps implicitly, in some form of filter) position measurements made on the ground, and can contribute to the job of defining the high-frequency components of trajectory.

Because these devices which "cooperate" with test ranges and are not normally a part of the avionics complement of operational aircraft, some means must be found to attach them to the airplanes during testing or training. The most common method is to attach them the way weapons are attached--i.e., in the form of some type of externally-carried pod.

In some classes of testing--particularly R&D tests--the necessary cooperative instruments may be carried internally, and special antennas or other structures mounted on the fuselage or elsewhere on the aircraft skin. However, for operational tests and

training situations, this option rarely, if ever, exists, because of the "no-mod" rule. This "rule," which is nearly a universally-observed unwritten law, simply says that there will be no modification of operational aircraft. Of course, these are exactly the aircraft which are involved in operational testing and training. This "no-mod" rule is quite understandable from the viewpoint of a commander of an operational squadron. Since his primary responsibility is to be prepared to go to war at a moment's notice, he is naturally quite reluctant to permit any surgery in the electronic guts of his airplanes, no matter how well-intentioned. So, test instrumentation and "cooperating" electronics are packaged in pods and carried on weapon stations.

#### 4.6.7.2.2 Limitations of Instrumentation Pods

As a result, there has been a proliferation of pods of different sizes, shapes, contents, and functions. Elsewhere in this document, the attempts by TESPO to consolidate test instrumentation pods into a Standard Airborne Instrumentation System (SAIS) pod with modular, interchangeable functional sections is described. But SAIS is at best only a partial, interim solution. There are several reasons.

First, SAIS cannot be very cheap. If the SAIS concept results in saving money, it will be because the logistic support for instrumentation pods can be reduced and consolidated, and because large quantity procurements can help keep unit costs down. But each SAIS pod will necessarily still be quite expensive. For example, the SAIS is expected to perform, in one of its configurations, the functions of the Airborne Instrumentation System (AIS) pod associated with the Air Combat Maneuvering Instrumentation (ACMI) System, described elsewhere in this document. AIS pods currently cost more than $100,000 each.

This introduces a second point, which the AIS pod illustrates well. The "no mod" rule often forces pod designers to duplicate, in the pod, measurements which are already being made more accurately by expensive

avionics systems located only a few feet away--inside the aircraft. The AIS pod contains a pitot-static system and pressure transducers, inertial elements to measure accelerations and attitude rates, and a computer to integrate these to produce estimates of attitude and velocity, duplicating the functions of the aircraft's own central air data computer and navigation system. Some may feel that such duplication is desirable or even necessary, and argue that it is dishonest, if not incestuous, to accept the avionics system outputs of the aircraft under test without an independent check. As a practical matter, however, the pod-mounted independent inertial instruments indicated above cannot attain the accuracy required to "check" or compete with an internally-mounted INS, because they must operate within the limited space, weight, power and a mechanical environment of vibration and buffeting, which is characteristic of pods. Similarly, the pitot static system in the pod cannot hope to be as well-calibrated for the peculiarities of airflows (at all of the various stations of the many aircraft types which may carry it) as the air-data system built into the airframe. Thus, the "independent check" is largely imaginary -- and usually unnecessary, since R&D tests will have already established the technical characteristics of aircraft avionics, and these are rarely at issue during operational testing or training.

But pods are unsatisfactory for a more basic reason: no access to internally-generated signals which convey the interactions between man and machine. Because OT&E and training are principally concerned with this interface (Is the machine suitable for use by operational forces? How can people be trained to get the most out of this machine?) it is not surprising that such events as crew switch actions to select and prepare weapons, radar lock-on, break-lock, key weapon and avionics system status and readiness indicators, RHAW outputs, selection of ECM choices, etc., are typical of the action-reaction data often needed (and seldom satisfactorily collected) during OT&E. These information-rich data elements can only be obtained from inside the aircraft.

#### 4.6.7.2.3 Another Alternative

It is therefore reasonable to expect that a fruitful opportunity exists to improve Air Force OT&E and training capability by incorporating, in production-model aircraft intended for operational forces, specific technical provisions to facilitate the extraction of data from aircraft avionics, fire-control, and electronic warfare systems for operational test and training purposes, while still adhering to the "no-mod" rule. Specifically, the basic idea is to incorporate, as "standard" in every operational aircraft of a given type, wiring and any necessary signal-conditioning equipment which would permit the addition of recording and/or telemetry equipment in a simple way (e.g., "plugged in" at a "common data point") when needed for a particular operational test or training mission. The advent of micro miniature data-handling/computing hardware, and particularly, the multiplexed, digital data-bus concept for aircraft avionics and weapons control systems adds credibility to the supposition that the cost and penalty of weight, volume, and power consumption of such wiring and necessary electronics associated with such a data-extraction "plug" could be made a negligibly small percentage of the cost, weight, volume and power of the aircraft's avionics system.

Significantly, the necessary engineering to determine methods by which such signals can be formatted and extracted is alreay accomplished to a large degree in the outfitting of prototype aircraft Development Test and Evaluation. While it is not suggested that DT&E instrumentation be retained in production aircraft, the design of a "common data point" with reduced, yet flexible capability suitable for support of OT&E and training can obviously benefit from the prior engineering and development of DT&E instrumentation and data-collection systems. An example of this is the McDonnell Mini-Integrated Data System (MIDS) (Reference a) which is essentially a reduced, or "austere" adaption of techniques used for the F-15 DT&E flight test data collection.

A typical "shopping list" of data elements of interest in many OTT&E or training situations is presented in Table 4.5. Availability and accuracy of these

**Table 4.5**

Typical Common Data-Point Signals--Tactical Aircraft

| Data Item | Source |
|---|---|
| Time | Internal Clock |
| Heading | Nav. of AHRS |
| Pitch | Nav. of AHRS |
| Roll | Nav. of AHRS |
| X Velocity | Nav System |
| Y Velocity | Nav System |
| Z Velocity | Nav System |
| Normal Acceleration | Added pkg. or Nav |
| Longitudinal Acceleration | Added pkg. or Nav |
| Lateral Acceleration | Added pkg. or Nav |
| Attack Angle | Aircraft AA Sensor |
| Side-Slip Angle | Aircraft Sensor |
| FCR Operating Mode | Fire-Control Radar |
| FCR Antenna Bearing | Fire-Control Radar |
| FCR Antenna Elevation | Fire-Control Radar |
| FCR Range | Fire-Control Radar |
| Pressure Altitude | Air Data System |
| True Airspeed | Air Data System |
| Outside Air Temperature | Air Data System |
| Clearance Altitude | Radar Altimeter |
| IFF/SIF Reply Code | IFF System |
| Roll Rate | Nav. or added Sensor |
| Pitch Rate | Nav. or added Sensor |
| Yaw Rate | Nav. or added Sensor |
| Latitude (Coarse & Fine) | Nav. System |
| Longitude (Coarse & Fine) | Nav. System |

Table 4.5 (Continued)

| Data Item | Source |
| --- | --- |
| Weapons Release Modes: | |
| Toss | Cockpit Switch Settings |
| Stik/Toss | Cockpit Switch Settings |
| Loft | Cockpit Switch Settings |
| OTS/Toss | Cockpit Switch Settings |
| Ballistic | Cockpit Switch Settings |
| Direct | Cockpit Switch Settings |
| Ripple | Cockpit Switch Settings |
| Weapons Feedback and Interface Signals: | |
| Ready to Fire | Missile Umbilical |
| Lock-on | Missile Umbilical |
| In-Range | Weapon-Control Computer |
| In-Envelope | Weapon-Control Computer |
| Seeker Look angles | Missile Umbilical |
| English Bias | Weapon-Control Computer |
| VTAS/SEAM | Weapon-Control Computer |
| Pylon Release Signals | Aircraft Weapon Stations |
| Stations Occupied | Aircraft Weapon Stations |
| Gun Rounds Remaining | Weapon-Control Computer |
| Bomb Button | Cockpit Switches |
| Gun Trigger | Cockpit Switches |
| Master Arm | Cockpit Switches |
| Navigation System Update | Cockpit Switches |
| Gun Camera On (If Installed) | Gun Camera Control |
| Strike Camera On (If Carried) | Strike Camera Control |
| Fuel Remaining | |
| Afterburner Status | |
| Speed-brake Deployment | |

Table 4.5 (Continued)

| | |
|---|---|
| RHAW Signals: | |
| Mode<br>Threat Indications | RHAW system |
| ECM Switchology: | |
| Mode Selection<br>On/Off<br>Chaff Release | EW Control System |
| TISEO System Controls | (if carried) |
| Laser Designator Controls<br>Laser Range | (if a laser system is aboard) |
| BIT Failure Indications | Built-in test equipment |

measurements will vary in accordance with the type and mission of the aircraft, and with its particular mix of on-board systems. For this reason, and to provide adaptability to meet unforeseen needs of future tests, some flexibility, or programmability of selection from such a shopping list must be a basic characteristic of the technical implementation. While "standard" telemetry or recording formats are a reasonable goal, it will probably be necessary to compromise on the degree of standardization of data frame structures and content. Standardization of physical electrical connectors is very desirable, but not mandatory.

This is not a new idea. Air Defense Command's 4756th Test Squadron at Tyndall AFB routinely modifies F-106's to add "common data point" wiring and signal-conditioning electronics to extract information in support of its mission to conduct OT&E for ADC. A November 1969 IEEE article (Reference b) co-authored by Colonel C. R. Phillips (USAF, Ret) stressed the need to plan, from the start, to obtain the data necessary for "combat effectiveness" evaluations, in Service Tests, OT&E, and even on into combat, with the necessary equipment to obtain this information carried as an essential component of the system itself. A 1966 WSEG Report (Reference c) noted the paucity of useful information being obtained from Southeast Asia air operations, identified the types of information needed, and suggested instrumentation techniques. This report prompted Dr. Foster (DDR&E) to encourage Joint Task Force Two to develop and demonstrate the feasibility of a small, built-in airborne data-collection system (Reference d) along the lines suggested by WSEG. These examples convey a common message: Exploit the onboard instruments and data sources available in operational aircraft.

Though the idea is not new, these are some important recent technological advances which make its implementation much simpler and more economical than ever before. The most significant of these is the "digital airplane" concept of avionics systems - or more officially, Digital Aircraft Information System (DAIS) (Reference e). This concept being implemented in the B-1, F-15, and F-16 involves the intercommunication and time-sharing of a central computer among a number of sensors, avionics,

and weapons control systems via a digital "party line," i.e., a multiplexed data-bus which serves as the communication medium among the several aircraft systems. Its importance to the provision of a "common data point" for access to aircraft data sources lies in the fact that this party line provides such access already, without installing additional wiring and signal-conditioning equipment in the aircraft. This means that the required capability can be furnished by making provision in the aircraft for adding a device to "tap" this party line, with a programmable capability to pick-off data items of interest as they appear on the line and reformat them for transmission to the ground via conventional telemetry or air-to-ground data link. Thus the additional weight, space, and power requirement imposed on operational aircraft can be made very small, and truly insignificant, if the capability is planned as a part of the DAIS design.

4.6.7.2.4 Current Status

In March 1975 TESPO initiated an investigation of the possibilities for such exploitation in the current and coming generation of tactical operational aircraft, at a very low level effort (two man-months) in parallel with its contractual study of the SAIS pod. This two-man-month effort included visits and discussions with representative of ADTC, 4756th Test Wing (Tyndall AFB), ADC (SPOs for F-15, F-16, F-5, EF-111 and A-10 plus the Engineering Directorate), Air Force Avionics Laboratory, F-15 Joint Test Force at Edwards AFB, Northrop, and McDonnell-Douglas. Without exception, the individuals contacted offered encouragement that the concept is a "good idea," "long overdue," etc., though aircraft SPOs predictably voiced some reservations on the possibility of getting it into their aircraft.

In the process of this investigation several other potentially important uses for the same data-extraction capability emerged, aside from the principal motivation to enhance OT&E and training. These are discussed briefly below:

a. Diagnostic Tool for Maintenance. If the "data-pickoff box" and a recorder were carried routinely, such a facility could be extremely valuable for corrective or preventive maintenance, particularly in resolving the frustrating crew reports of system failures which seem to "heal themselves" the moment the aircraft lands. In this role, the "common data point" would be an extension of the Built-In Test (BIT) concept, for which precedent is already well-established.

b. Fatigue-Life Accounting. Additional equipment and wiring to measure and record the occurrence of high-g-loading have been installed in combat aircraft for this purpose alone. The common data point, with a suitable recorder, could obviously serve this purpose.

c. A Tool for Analysis of Combat. The possibility to monitor and record our own avionics systems, particularly the radar and RHAW, affords an opportunity to analyze the enemy's counters to our tactics and equipment, and to pinpoint problems in our own equipment or facilities.

4.6.7.2.5 Conclusions and Recommendations

Within the limited effort thus far devoted, it has not been possible to determine the impact on cost or schedule to implement a common data point capability into any given aircraft. However, some tentative conclusions and recommendations can be stated:

a. For the F-15, the multiplexed data-bus permits a very simple and straightforward implementation. In fact, the McDonnell-developed MIDS provides essentially the capability described above. However, MIDS is not an Air Force requirement, and no plans exist for quantity procurement. Similarly, the DAIS concept of avionics in the F-16 should facilitate provision of the capability in that aircraft, if a requirement were stated for it. The F-5E has more conventional avionics, but a modification to provide a common data point is certainly feasible. Especially for those F-5Es to be assigned as an "aggressor squadron" such a modification seems well worthwhile, since such an aircraft will be in constant use in training and test situations.

The austere avionics complement of the A-10, and the limited wiring access through the titanium cockpit shield makes an installation less attractive, and more difficult. Insufficient information was obtained on the EF-111 to permit a judgment, though SPO members contacted were interested in the potential of the idea for maintenance assistance of the complex electronics for that aircraft.

Actions recommended, to continue or follow-up the investigation, are along three concurrent, mutually supporting lines:

- Initiate funded contractual studies to determine technical methods, cost and schedule to incorporate a common data point in the F-15, F-16 and F-5.

- Solicit comments, suggestions, and requirements from using commands, particularly TAC, ADC, and ATC.

- Identify sources of funding from allocations to "OTT&E Improvement" which may be used for common data point development, and provide assistance to Air Staff in modifying the ROCs for one or all three of these aircraft and generating an appropriate PMD (or addition to a current PMD) to undertake the effort.

4.6.7.2.6 References

a. F-15 Integrated Data System, McDonnell Aircraft Company Report H277-1, 30 Sep 71, Revised 12 Jul 74.

b. Walker, N. K., and Phillips, C. R., "The Need for Allocating Resources to Combat Effectiveness Measurements from Initial R&D to Obsolescence," IEEE Transactions on Engineering Management, Vol 16, No. 4, Nov 69.

c. Requirements for Data from Combat Operations in Southeast Asia, Weapon Systems Evaluation Group Report No. 101, Aug 66 (SECRET).

d. Combat Aircraft Recording and Data System (CARDS) Description and Flight Test Report, Joint Chiefs of Staff Report JTF-2CARDS, Nov 68.

e. Aircraft Internal Time Division Multiplex Data Bus, Military Standard MIL-STD-1553 (USAF), 30 Aug 73.

4.6.8 Special Considerations for Calibration and Related Matters

In the application of instrumentation in general and TSPI systems in particular the results obtained are reliable only to the extent that the orientation and time calibration are reliable. This reliability must be considered with respect to an acceptable standard for the mission, and it should be understood that the standards may vary according to the requirements of the mission.

The two subsections which follow discuss at some length the matters of orientation and time standardization.

4.6.8.1 Calibration

4.6.8.1.1 Introduction

This section discusses techniques and their limitations for calibration of range instrumentation, such as radars, theodolite arrays and multilateration systems. Calibration is performed to ensure that measurements made with an instrument will be defined relative to the true value of the quantity measured within a defined error tolerance or specified accuracy. No attempt is made to describe how calibration should be done, emphasis instead is on what is necessary to ensure or improve tracking system accuracy. Accuracy of a measurement (or the mean of a number of similar measurements) refers to the extent which a measurement conforms to the true or absolute value. It applies to timing, random (nondeterministic or noise-like) and systematic (deterministic) components of error (see Section 4.6.8.1.2 for discussion of errors). Systematic errors include angle and position alignment ment errors as well as equipment, environmental and target motion induced anomalies. Their characteristics are such that they may be deterministically modeled. A given reading also may be characterized by its precision -- the quality of being exactly or sharply defined and free from random errors. Thus, an accuracy specification must govern all errors in the system, and must allow a greater

tolerance than the precision specification which covers only random errors. Instrumentation manufacturers provide a precision specification and often accuracy relative to the base alignment of the instrument. The accuracy achievable in the field will depend on how it is operated, maintained and calibrated.

Resolution is also used in connection with accuracy and precision. In the usual connotation, resolution is the ability of the sensor to separate closely spaced targets. For a tracking system, one can speak of both range resolution and angle resolution.

The data produced by an instrument are subject to timing, random, and systematic errors. Calibration is the process whereby systematic instrument errors are discovered/observed, sorted out or correlated with the source of error and either removed or modeled; i.e., error models for each error source produced. The error models are then used to remove the errors from the data produced (post flight data processing) or, alternatively, may be used to provide additions to the instrument tracking system in such a way as to prevent errors from occurring (in-loop processing). In either case, a computer of other mechanization is needed for the error removal process. The use of a computer in the calibration process to control the observational procedure and automate the error modeling process is advantageous for repeatability and time saving.

Observability; i.e., the ability to note errors, is important in each step of the calibration process. However, it is most important in the error removal process, where it is most often lacking. Only by observing the end effect of the calibration process can one have confidence in the accuracy of the system. In fact, if errors are observed after error removal, then iteration back through the calibration process to refine error models and/or control the removal process is necessary until the required system accuracy (or all the system is capable of) is achieved. A separate, acceptable standard to compare against is necessary for the final evaluation of system accuracy.

Each tracking system will have its own unique restrictions on the calibration techniques/processes available and/or implementable. One is forced to make do with what can be made available. Within these constraints, the best accuracy results can only be achieved through meticulous attention to detail throughout the calibration process. Calibration checks should be performed often enough to ensure the accuracy of the tracking data; e.g., before, during (if possible) and after a measurement mission.

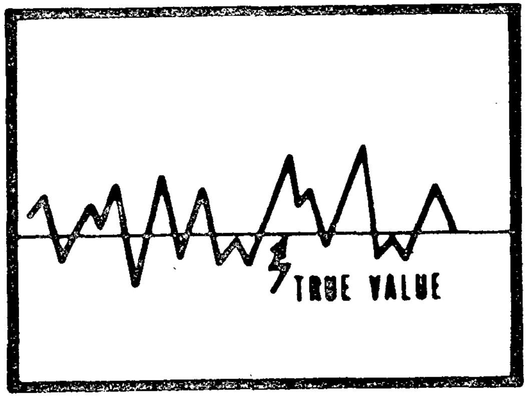
4.6.8.1.2 Error Sources (Figure 4-28)

The factors contributing to the accuracy of tracking systems are multiple in number and complex in nature. The various errors which must be determined affect the system accuracy to different degrees and in some cases also interact with other errors. Basically, the total error in a given measurement may be defined as the difference between the measured value, as indicated by the sensor/instrument, and the true value. It is necessary that all of the deterministic errors inherent in the instrument be ascertained in order that a reasonable error budget can be established and significant errors models and compensated for if necessary to achieve the required accuracy.

It is common practice to divide errors into two categories: random (nondeterministic) and systematic (or deterministic) errors. Time, which is treated as an independent variable in processing data, also can be a serious source of error. Care must be taken to ensure time accuracy and that position and position derivatives are correctly time associated. The random errors are not correctable via calibration, but their effects can be reduced by smoothing. The smoothing of the random errors is performed to determine the mean over the data span. The mean value, if different from zero, is used as a bias in the error model. The systematic errors are characterized by being deterministic (predictable) and are amenable to correction by a process of calibration applied to the instrument before measurements are made.

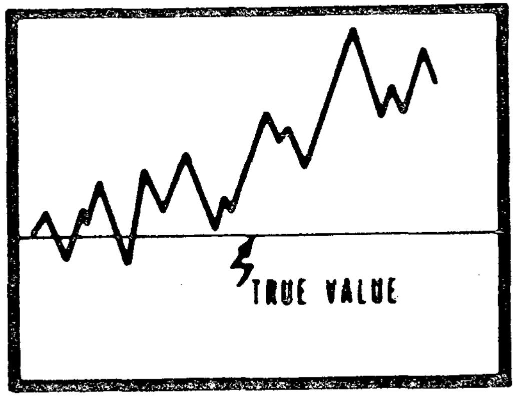
# TRACKING ERRORS

**RANDOM ERROR COMPONENTS**



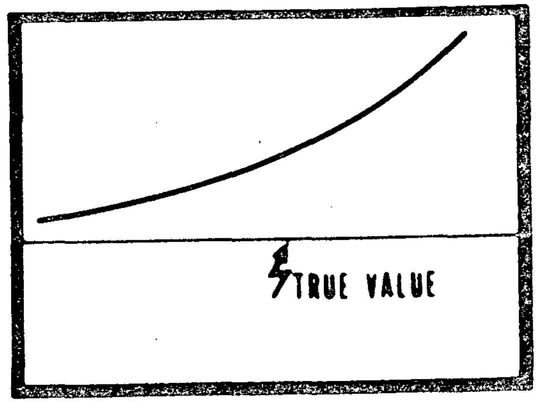

- RAPID FLUCTUATION NOISE-LIKE
- ZERO MEAN
- CAN BE AVERAGED TOWARD ZERO
- ANY ONE DATA POINT HAS ERROR

**TRACKING DATA**




- WILL NEVER KNOW TRUE VALUE
- MANY POSSIBLE INTERPRETATIONS WHEN PROCESSED

**DETERMINISTIC (SYSTEMATIC) ERROR COMPONENT**




- SLOWLY VARYING (CANNOT BE AVERAGED OUT)
- POSSIBLE TO OBSERVE APRIORI
- DEVELOP ERROR MODELS
- REMOVE FROM DATA
- EXTERNAL REFERENCE NEEDED TO CONFIRM

Figure 4-28

The total instrument error is a combination of a large number of individual errors. Table 4.6 summarizes the significant error sources, together with remarks on each. Not all of the potential errors identified will be pertinent to a well-designed tracking radar, nor to electronic tracking systems, such as multilateration system.

Observing sensor/instrument errors requires a separate calibration or evaluation, reference sensor (or sensors). An additional source of error is introduced by the reference sensor(s) against which the sensor/instrument is being compared. The errors from this source (as applicable in Table 4.6) must be isolated from the errors of the instrument being calibrated; i.e., the pertinent reference sensor(s) errors must be adequately modeled and removed or compensated for prior to use in calibration.

#### 4.6.8.1.3 Calibration Techniques/Procedures

The purpose of calibration of instruments is to assure that measurements made with each instrument will represent the true value of the quantity measured within a defined error tolerance or specified accuracy. The calibration can be done in several different ways, but the accuracy of the calibration will differ as a function of the method chosen. The choice of calibration technique in each instance will be made on the basis of availability, adapatability, accuracy, and cost.

An interesting example is in the Federal Aviation Regulation (FAR 91.25) requiring periodic calibration checks of the airborne very high frequency omni range (VOR) equipment for instrument flight rules (IRF) operation. This regulation specifies no less than five acceptable VOR calibration check methods, with two different measurement tolerances being acceptable. The technique chosen will depend primarily on availability and the resulting accuracy verification will vary but will be within the tolerance specified. Note that the procedures of FAR 91.25 are only for a calibration check or verification of accuracy. If the instrument is out of tolerance, then repair and/or recalibration is indicated. This example is intended to illustrate the

TABLE 4.6: EXAMPLES OF ERROR SOURCES

| ERRORS SOURCES | TYPE OF ERROR: SYSTEMATIC | TYPE OF ERROR: RANDOM | REMARKS |
|---|---|---|---|
| MOUNT ANOMALIES | DROOP | | ERRORS ARE DEVELOPED BY VARIABLE DEFLECTIONS CAUSED BY THE FORCE OF GRAVITY ON THE MOVING STRUCTURAL COMPONENTS. THE DEFLECTION ERROR IN GENERAL IS A COSINE FUNCTION OF ELEVATION ANGLE. |
| " | AZIMUTH ALIGNMENT | | THE DEVIATION FROM TRUE NORTH OF THE ZERO AZIMUTH SETTING IS TO BE CONSIDERED AN ERROR. ANY DRIFT IN THE ELECTRICAL BORESIGHT CAUSES ERROR. |
| " | LEVELING | | THE DEVIATION FROM TRUE VERTICAL IS AN ERROR. MIS-LEVELING PRODUCES BOTH AZIMUTH AND ELEVATION ERRORS. |
| " | NON-ORTHOGONALITY OF AXES | | NON-ORTHOGONALITY BETWEEN THE AXES PRODUCES AN AZIMUTH ERROR APPROXIMATELY PROPORTIONAL TO THE TANGENT OF THE ELEVATION ANGLE. |
| " | BEARING RACE IRREGULARITIES | BEARING BALL IRREGULARI-TIES | ERRORS ARE SIMILAR TO THOSE PRODUCED BY MISLEVEL-ING AND NON-ORTHOGONALITY, EXCEPT THAT THEY MAY BE RANDOM IN NATURE. |
| " | SERVO UNBALANCE AND DRIFT | SERVO NOISE | NON-LINEARITIES IN SERVO COMPONENTS CAN INTRODUCE AN UNBALANCE WHICH PRODUCES A BEAM SHIFT. SERVO AMPLIFIERS, DRIVE SYSTEM, FRICTIONAL IRREGULARITIES, ETC., CAN PRODUCE A RANDOM NOISE ERROR. |
| " | ENCODER ZERO SET & MISALIGNMENT | ENCODER NON-LINEARITY AND GRANULARITY | MISALIGNMENT OF THE ENCODER WITH THE ANTENNA AXIS CAUSES SYSTEMATIC ERROR. ENCODER NON-LINEARITY AND RESOLUTION CAN LEAD TO RANDOM ERRORS. |
| TRACKING DEPENDENT | BEACON DELAY | TARGET SCIN-TILLATION OR BEACON MODU-LATION OR BEACON JITTER | AMPLITUDE FLUCTUATION OF TARGET RETURN SIGNAL CAUSED BY DESTRUCTIVE AND CONSTRUCTIVE INTERFERENCE OF SIGNALS FROM VARIOUS REFLECTING PARTS OF TARGET OR BY MODULATION OR TIME DELAY JITTER OF BEACON, IF USED. "FIXED" DELAY MAY VARY WITH RECEIVED SIGNAL INTENSITY AT THE BEACON. |

TABLE 4.6: EXAMPLES OF ERROR SOURCES (CONT.)

| ERRORS SOURCES | TYPE OF ERROR: SYSTEMATIC | TYPE OF ERROR: RANDOM | REMARKS |
|---|---|---|---|
| TRACKING DEPENDENT | RECEIVER PHASING | RECEIVER NOISE | INCORRECT MONOPULSE CHANNEL PHASING (AND DRIFT) WILL RESULT IN AN ANGULAR ERROR. RECEIVER NOISE CAUSES ANGULAR AND TIME-INTERVAL MEASUREMENT FLUCTUATIONS. |
| SUPPORTING INSTRUMENTATION | SURVEY | | ERROR IN SURVEYED LOCATION LEADS TO ERROR IN ABSOLUTE ACCURACY. FOR DISTRIBUTED SYSTEM, SURVEY ERROR CAUSES MEASUREMENT ERROR. |
| " | MEAN STABILITY/ POINTING ACCURACY OF BORESIGHT TELESCOPE | JITTER IN BORESIGHT TELESCOPE | FOR A TYPICAL TRACKING RADAR, THE BORESIGHT TELESCOPE PROVIDES THE BASIC REFERENCE FOR ALIGNMENT. ERRORS IN THE OPTICS WILL APPEAR DIRECTLY AS ERRORS IN THE POINTING ACCURACY. |
| " | OPTICS RESOLUTION | | TRACKING SYSTEM ANGULAR ALIGNMENT CAN BE NO BETTER THAN THE ANGULAR ACCURACY OF THE OPTICS. |
| ENVIRONMENTAL | TIME | | PROPAGATION CONDITIONS, PARTICULARLY FOR WWV, CAN INFLUENCE THE TIME ACCURACY OF SETTING THE LOCAL "CLOCK" AT THE INSTRUMENT. IT CAN ALSO LIMIT THE ACCURACY FOR A DISTRIBUTIONAL TIME SYSTEM (FROM A CENTRAL STANDARD). |
| " | STEADY WIND | WIND GUSTS | ERRORS DEVELOPED BY A STEADY WIND ARE A FUNCTION OF ANTENNA POSITION RELATIVE TO THE WIND DIRECTION. WIND GUSTS CAUSE VARIABLE DEFLECTIONS. |
| " | SOLAR HEATING/ AMBIENT TEMPERATURE CHANGE | | TEMPERATURE GRADIENTS RESULT IN UNEVEN EXPANSION WHICH DISTORTS THE STRUCTURE AND INTRODUCES ERRORS. IT MAY RESULT FROM SOLAR HEATING OR UNCONTROLLED AMBIENT TEMPERATURE. |

TABLE 4.6: EXAMPLES OF ERROR SOURCES (CONT.)

| ERRORS SOURCES | TYPE OF ERROR: SYSTEMATIC | TYPE OF ERROR: RANDOM | REMARKS |
|---|---|---|---|
| ENVIRONMENTAL | | ATMOSPHERIC MODULATION OF CALIBRATION TARGET | TRACKING SYSTEM ANGULAR ALIGNMENT CAN BE NO BETTER THAN THE ANGULAR ACCURACY OF THE OPTICS. |
| " | AVERAGE REFRACTION OF TROPOSPHERE | IRREGULARITIES OF TROPOSPHERIC REFRACTION | BOTH RADIO AND OPTICAL WAVES WILL UNDERGO ATMOSPHERIC REFRACTION AS A FUNCTION OF ELEVATION ANGLE AND RANGE. THE EFFECT FOR THE TWO WAVELENGTHS WILL DIFFER BY ABOUT 12 ARC SECONDS AT 15-20$^{\circ}$ ELEVATION ANGLE, MORE AT LOWER ANGLES. |
| " | | EFFECT OF MULTIPATH ON A MOVING TARGET | GROUND TERRAIN REFLECTIONS INTRODUCE ANGLE ERROR AT SMALL ELEVATION ANGLES, ERROR TENDS TO BE IN THE OPPOSITE DIRECTION FROM THE REFRACTIVE ERROR. |
| TARGET MOTION INDUCED | DYNAMIC LAG (APPARENT ACCELERATION) | | A CONSTANT VELOCITY TARGET WILL YIELD AN APPARENT ANGULAR ACCELERATION (AND HIGHER DERIVATIVES) TO A SINGLE POINT TRACKING INSTRUMENT AS IT APPROACHES, PASSES AND RECEDES FROM THE INSTRUMENT LOCATION. |
| " | GEOMETRIVE DILUTION OF PRECISION (GDOP) | | ACCURACY IS A FUNCTION OF TARGET LOCATION. |
| ENVIRONMENTAL | | TARGET GLINT | ANGULAR NOISE CAUSED BY WANDERING OF THE TARGET CENTER OF REFLECTION (APPARENT CENTER MAY BE OUTSIDE THE TARGET CONFINES SOME PERCENTAGE OF THE TIME). |
| DATA PROCESSING | INCORRECT ERROR MODELS, TIME-TAGGING OF DERIVATIVES, ILL-DEFINED STARTING CONDITIONS | INADEQUATE NOISE STATISTICS | IT IS IMPORTANT THAT ALL ASPECTS OF THE TRACKING SYSTEM/PROCESS BE WELL UNDERSTOOD, IF THE DATA PROCESSING IS TO COMPENSATE FOR DETERMINISTIC AND SMOOTH OUT RANDOM ERRORS. |

TABLE 4.6: EXAMPLES OF ERROR SOURCES (CONT.)

| ERRORS SOURCES | TYPE OF ERROR | | REMARKS |
|---|---|---|---|
| | SYSTEMATIC | RANDOM | |
| DATA PROCESSING | LINEARITY OF DATA AND/OR PROCESS | | MANY PROCESSES SUCH AS LEAST SQUARES, MAXIMUM LIKELIHOOD, AND KALMAN FILTER ARE NOT TOLERANT OF NON-LINEAR DATA. |
| " | AVERAGE VALUED DERIVATIVES | | DERIVATIVES BASED ON POSITION AVERAGING WILL BE IN ERROR FOR MANEUVERING TARGETS, DEPENDING ON DURATION OF AVERAGING PERIOD. |

need to approach the calibration problem in a flexible and imaginative manner, with due consideration to practicality, the accuracy actually required, and the degree of assurance necessary.

The same philosophy applies to test range tracking instrumentation. A variety of calibration techniques/procedures are possible and the choice depends on what is "best" for a given installation and accuracy requirement.

Calibration in the context used here involves the observation of systematic errors, modeling them and error removal and/or compensation. Different levels of calibration are currently used, partly as dictated by accuracy requirements and partly due to limitations inherent with the instrumentation.

Many radars, for example, are calibrated only with respect to a boresight target and instrument level. This accommodates zero setting of the angle and instrument level. This accommodates zero setting of the angle and range encoders and leveling to local gravity. An integral system computer is not available and most of the systematic errors are not observed (detected) or corrected.

Trajectory instrumentation is used to track aircraft, missiles, and other objects for performance evaluation. The product is a single vector composed of position, velocity and acceleration, all at the same time (TPVA), which adequately describes the motion of a target. If the target is maneuvering a series of vectors (TPVA) which approach instantaneous rather than average values are required. The accuracy of the trajectory observation is determined by the accuracy of the time position derivative of significance.

#### 4.6.8.1.3.1 Error Removal

A tracking instrument with a computer (the computer in some cases may not be colocated) can accomplish a higher level of calibration. The compensation for more of the errors influencing tracking accuracy. Note that the "computer" need not be a digital machine to quality--analog devices for error compensation also are used.

The computer may be used with the instrument either for post flight or in-loop data processing for error correction. In a calibration sense, it provides the means of accommodating a variety of systematic error models (droop, non-orthogonality, refraction, etc.) and modifying the tracking system and/or data accordingly to remove the effect of the errors. Note that when used post flight, the data processing is dependent on *a priori* knowledge of the error models; i.e., there is low observability (detectability) of the correctness of the error modeling and removal process. Inadequate error correction and/or incorrect use of one or more individual error models could occur and not be noted. In the absence of observability, there can be no assurance that the desired accuracy improvement is achieved. Making the judgment that the trajectories obtained appear "reasonable" does not substitute for observability. On-line data processing for error removal; i.e., use of error calibration models, may be implemented either within the radar tracking control system (in-loop) or outside of the tracking loop to correct the measured data for subsequent use. Even though on-line, the latter technique is basically post-flight data processing. However, it does offer potential for on-line comparison of data with a reference tracker to verify correctness of error removal. In-loop implementation for error compensation is also possible. Separation of error sources is facilitated by in-loop processing, as is error modeling and observation of correctness of error removal.

All significant systematic error sources (equipment, dynamic and environmental anomalies) must be modeled in the calibration process to allow adjustment to correct for the errors. Observability is necessary at each step in the calibration process, including verification of the correctness of error removal. Accuracy of the error model terms determine the accuracy of the tracking system, assuming no timing errors. How many of the potential error sources must be modeled and to what accuracy depends on the accuracy requirements placed on the instrument. In general, an error source should be modeled and corrected for if its potential error contribution is as much as one-tenth of the allowable inaccuracy (total error) for the instrument. Calibration checks must be performed often enough to ensure the accuracy of the system and to allow compensation for errors which may vary with time.

### 4.6.8.1.3.2 Error Observation/Identificiation

A number of techniques are used for observing and/or modeling systematic errors as part of the process of removing their effects. These techniques include:

- Factory calibration
- Use of calibration targets
  - One or more towers
  - Use of the stars
  - Dynamic targets
- Comparison with a "reference" tracker
- Multiple radar comparisons

Factory calibration can be used to identify and model many of the single sensor systematic error anomalies; e.g., slew, non-orthogonality, droop, encoder non-linearity, etc. Use of these models to remove errors requires a computer. Equipment changes which affect the errors modeled could occur in moving and installing the instrument in the field. The error terms also could change with time due to aging and wear of the instrument. In many cases, however, these factory determined error models are all that would be available for correction purposes. Models for other systematic errors; e.g., refraction, transit time, apparent acceleration, etc., also can be developed by the manufacturer. Their use in the field without some means of observing their validity is suspect for all of the factory models and may not yield the desired accuracy result.

Use of calibration targets by tracking systems is common. Usually this consists of one calibration tower visible to the tracker at a surveyed location. Use of a single calibration target only allows the tracking system to achieve good static accuracy at one point. However, the tracker normally must be capable of accurately tracking dynamic targets throughout a hemisphere and accuracy will degrade as it is pointed away from the calibration point. The achievable accuracy elsewhere in the

tracking hemisphere will depend on the leveling accuracy, the integrity of the instrument, and the validity of any error modeling incorporated. Some means of error observation is necessary to ascertain accuracy throughout the tracking hemisphere. For many tracking radar installations, the accuracy requirements and instrument precision are such that care in leveling and orientation with a boresight tower is all that is required to achieve the needed accuracy. The ACMI is an example of a multilateration system which utilizes a single calibration target for calibration. The same comments apply if surveying accuracy is substituted for leveling accuracy.

In some cases, more than one calibration tower is used. Beyond forcing the static accuracy to be good at two or more points near zero elevation angle instead of one, the same comments apply.

A natural extension of the use of calibration towers is to look for calibration targets scattered throughout the tracking hemisphere. The stars are the only calibration targets (reference sources) available scattered throughout the tracking hemisphere and suitable for tracking system to autonomously (self) calibrate against. Too few radio stars (celestial point sources of radio frequency energy) are available for this purpose and only a few tracking radars are capable of detecting any radio stars. Thus, use of the stars by optical means are dictated for calibration. For a tracking radar, a boresight telescope with adequate resolution and capable of detecting a sufficiently large number of stars (even in daylight) is required. Given an appropriate tracking system and computer, the use of stars as calibration targets allows definition of systematic error terms (e.g., skew, non-orthogonality, droop, etc.), determination of up (local vertical) and North to an accuracy consistent with the resolution of the boresight telescope (or angle encoder resolution if worse than that of the telescope). Properly done, this can give the optical (boresight) system an absolute, static accuracy consistent with the system resolution. The systematic errors uniquely associated with the microwave (or laser) portion of the radar system must then be modeled and the radar portion of the radar system brought into coincidence with the optical system. This is done by tracking dynamic targets

with the radar which are also visible optically. Differences in atmospheric refraction at optical and microwave frequencies must be taken into account in this process.

The star calibration technique is the best available for autonomous, essentially static, self-calibration. It can and should be refined to verify tracking accuracy on dynamic targets. This can be done by using a second such tracking system, remotely located and autonomously calibrated against the stars. Driving the remote system with tracking data from the first, should cause the remote system to point to the target to within the calibration resolution. Using targets on near overhead passes of the remote system, small errors in time and/or relative geodetic location between the two systems can be observed and corrected.

Use of the stars for calibration may not be desirable or practical for all systems. Nevertheless, some means of observing tracking errors throughout the tracking hemisphere for subsequent removal and/or compensation is required if there are accuracy specifications for the tracking data to be obtained. Comparison of the tracking data on dynamic calibration targets; e.g., calibration aircraft, with the tracking data from a reference tracker can provide suitable hemispherical observability. An additional potential error source is introduced by the reference tracker against which the sensor/instrument is being compared. The errors from this source must be isolated from the errors of the instrument being calibrated; i.e., the reference tracker errors must be adequately modeled prior to its use in calibration. Ideally, the reference tracker should be more accurate than the instrument being calibrated and data should be available for comparison on line.

Finally, a technique which is sometimes used to force a consensus among a number of tracking systems. The consensus will define a "reference track" which in turn can be used to model the errors of any one of the tracking systems in order to attain better agreement of data. This achieves better agreement, but not necessarily better accuracy for a given tracking system. All of the tracking systems will have errors, and the resulting

consensus will also contain errors. Post flight data processing is used to derive the consensus track, for error model adjustment and for error removal. The most accurate system will be degraded, and the worst system improved if the systems are averaged. In a similar manner, either system can be forced to agree with the other. If used on line to compare systems, this technique may have some validity for calibration verification.

The techniques described above, for error observation or identification, basically define the approaches available for calibrating tracking systems. Being able to observe errors, and the degree of success in error removal, is critical to the calibration process. It is only after demonstrating an effective means of containing the significant error sources that one can speak of the accuracy of a tracking system. In many cases, a lower precision tracking system, but calibrated better, also would be capable of satisfying the accuracy requirements. In effect, precision in excess of that needed is being paid for. Optimum use of available calibration procedures may allow requirements to be met with a lower precision tracker at less cost.

4.6.8.1.3.3 Calibration of Distributed Systems

There are two types of distributed tracking systems: angle measuring systems, such as an array of theodolites, and multilateration systems, such as the Air Combat Maneuvering Range (ACMR) or the Range Measurement System (RMS-2/SCORE). Distributed sensor systems consist of two or more measurement sensors located some distance from each other. Each station makes a measurement of the target angle and/or range or time of arrival (TOA) and then a geometric process is used to extract target position from this data.

a. Theodolite Arrays. Two stations, measuring the azimuth and elevation angle of a target, are sufficient to establish the target position. Figure 4-29 shows the geometry of the situation.

Most TSPI accuracy requirements are specified in terms of ground-based coordinate systems (typically x = crossrange, y = downrange, and z = height). The equations used to establish the position (x, y, z) of the target are:

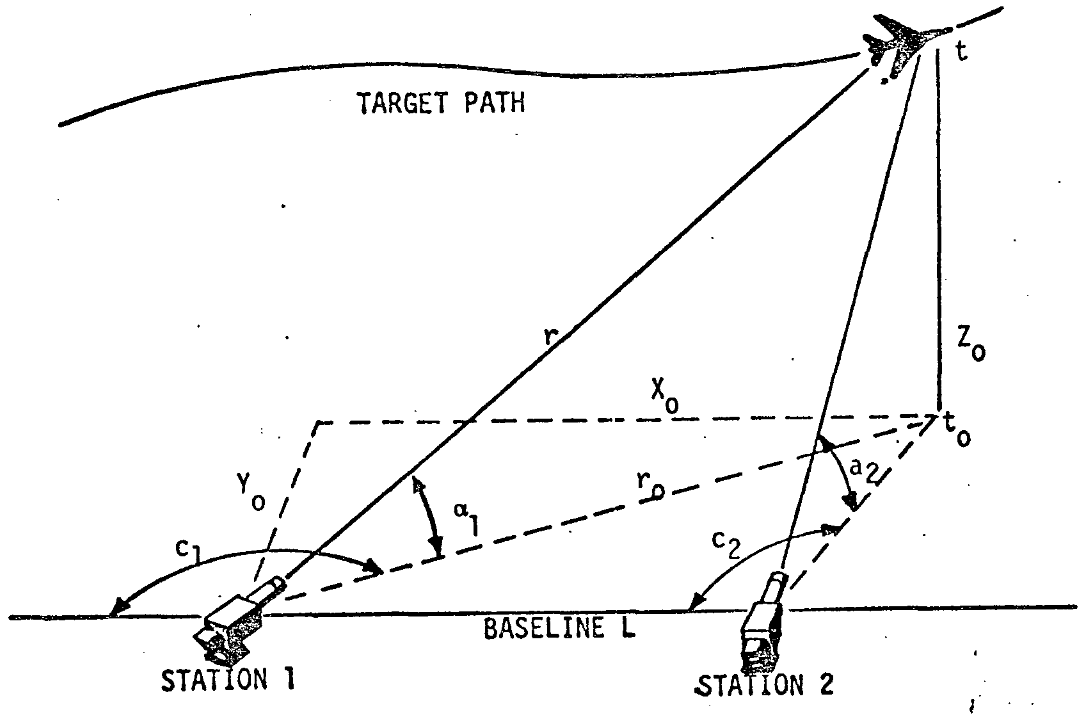



FIGURE 4-29: ANGLE MEASURING GEOMETRY

$$r_0 = \frac{L \sin (C_2)}{\sin (c_1 - c_2)}$$

$$r = \frac{r_0}{\cos (a_1)} = \frac{L \sin (c_2)}{\sin (c_1 - c_2) \cos (a_1)}$$

$$z_0 = r_0 \tan (a_1) = r \sin (a_1)$$

$$= \frac{L \sin (c_2) \sin (a_1)}{\sin (c_1 - c_2)}$$

$$x_0 = r_0 \cos (c_1) = \frac{L \sin (c_2) \cos (c_1)}{\sin (c_1 - c_2)}$$

Uncertainty is associated with all measurements. The position certainty is expressed as volume of uncertainty (VOU) which contains the target. If the measurements are orthogonal and of equal precision, the volume is described as a sphere. If the measurements are nonorthogonal, then the volume is larger and in the form of an ellipsoid. Since a distributed sensor system is in a practical sense nonorthogonal, the VOU of a distributed system is always an ellipsoid. The shape and orientation of the ellipsoid changes as the target position varies with respect to the sensors in the network. The VOU is that volume in which the target is always contained, but it does not specify the target location as a point. While the target must lie within this VOU, its probability of being at any particular point in the volume varies. Hence, a more precise error definition would be an ellipsoid of a constant probability. The probability ellipsoids change in shape and orientation as position changes. Maximum precision is achieved when the target positioned so that the angular measurements from two stations are at right angles to each other.

An optical system is advantageous for use as a position measurement device due to the ability to "see" the target and the smaller magnitude of systematic errors (due to instrument precision and a much smaller atmospheric refractivity at optical frequencies). A theodolite array is a post-flight system because processing to produce position is done after data collection. As with all post-flight systems, there is no observational check on results except possibly a closure reasonableness check.

A cinetheodolite is an optical sensor mounted on an elevation over azimuth mount. The pointing function is most often accomplished manually. Generally, all necessary data are contained in each frame of a photograph, frequently collected by a high-speed camera. Each frame displays time (preferably time of day), azimuth, elevation, the boresight center defined as an optically visible reticle, and an image of the target. Of particular interest is the method of collecting and displaying the instantaneous azimuth and elevation of the telescope. Several techniques are used: (1) Both azimuth and elevation are obtained using a direct reading optical train which displays a graduated scale fixed to the trunnion of each axis on the film, (2) A digitized value of azimuth and elevation are recorded on the film for electronic readout, and (3) The angle data are read directly into a central computer. The azimuth and elevation generally are not used to point the instrument, thus the angle reading does not introduce velocity and acceleration lags which would accrue if used for pointing. Apparent accelerations are seen in the azimuth and elevation axes; but, since there are no lags, apparent acceleration is automatically removed in the transformation to a rectilinear coordinate system.

The Contraves Electronic Optical Tracking System (EOTS) cinetheodolite is the basic unit used. It is designed to produce single frame images on 35mm film at rates from 5 to 30 frames per second. Several models are available: the EOTSC, EOTSD and EOTSF. Both the EOTSC and EOTSD are without digital readout capability, having projection scales upon which the azimuth and elevation are read off phtographically. Thus, information on the single tracked target is not available on-line. Coverage depends upon the size of the target being tracked

and the visibility conditions during the test. Instrument precision in both elevation and azimuth is 1 arc minute (.3 milliradian). Data reduction to determine the target angles is done manually and may require days to months depending upon the workload of the processing facility.

One example of an on-line cinetheodolite system makes use of digitized EOTSC Contraves cinetheodolite. On-line azimuth and elevation data on a single target are fed digitally to a central computer, which determines the x, y, and z coordinates of target position. Pointing of the cinetheodolites is done manually; the operator of each unit positions the cinetheodolite using a joystick and a sighting scope, aided by velocity and acceleration tracking information from the computer. When the unit is "on track" the operator signals the computer. Data rate to the computer is 20 samples per second with display data available at the rate of 5 samples per second.

Since the theodolite system measures the target offset from a reticle, the significance of the least bits of the azimuth encoder changes with respect to the traverse resolution of the sensor as a function of elevation angle. A secant correction must be applied to the left/right offset as a function of elevation angle in transforming to azimuth angle.

Although volume of uncertainty represents a statistical estimate of the target uncertainty, it does not translate to the accuracy of the total system, since the system contains other random and systematic errors influences. The systematic error model generally is assumed small and ignored. As an example, the results of refraction cause a sensor to point higher in elevation than the true angle to the target. Refraction has less significance at the optical region of the spectrum than at microwave frequencies. In many cases of theodolite data reduction, refraction corrections are not made in the fear that refraction is not well enough defined, and therefore, the correction may make the data worse instead of improving it. Theodolites are most often treated as the standard. Verification of their accuracy is rarely attempted.

b. Multilateration Systems. Basically, the multilateration trackers are electronic ranging systems which compute range to the target being tracked from three or more presurveyed locations and compute the target position. Being electronic, the system has great agility and can "simultaneously" track a number of targets. It also can easily intersperse "looks" at a calibration target(s) in with the target tracking to verify accuracy (at one point) and system integrity. The self-calibration thus is timely but limited in scope. Starting with two or three pre-surveyed sensor locations, a system may use its electronic ranging capability to self-survey in the rest of the sensor locations required (e.g., as is done with the RMS-2/SCORE). (Note that accuracy, including that of self-surveying if used, must be verified against a suitable standard to validate system accuracy.) Potentially, the multilateration system should be capable of good tracking accuracy, at least in the horizontal plane, for targets within or near the system. Geometrical dilution of precision (GDOP) and multipath effects will seriously degrade its capability to measure altitude accurately for relatively low altitude targets. Both the ACMI and the RMS/SCORE attempt to solve this altitude measurement problem through the use of an altitude indication telemetered from an aircraft.

Nothing within the multilateration system is capable of confirming measurement accuracy other than at the static calibration target point. If a known accuracy is required of the system, then some means of observing its tracking performance at representative points throughout the coverage volume is required. This can take the form of accuracy verification tests if it is deemed probable that the system does have adequate accuracy to meet mission requirements. However, if the verification tests identify accuracy deficiencies,[1]

[1]Note that the initial results of accuracy verification tests of the RMS-2, using the AEC theodolite array at Tonopah NV do indicate accuracy deficiencies, especially in altitude. Accuracy tests of the RMS/SCORE and the ACMR, either have not been made or are not available at this time.

then calibration procedures must be devised which would reconcile the deficiencies. The calibration process probably can be simplified as experience with the reliability/repeatability of the system is gained.

A calibration procedure using a reference tracker appears to be an appropriate choice for multilateration systems. The accuracy potential of the multilateration system, about 20 feet in horizontal measurements, puts stringent accuracy requirements on any system to be used as a reference tracker. The reference tracker itself must be calibrated and its accuracy verified to be better than that required of the multilateration system. Verification of the references tracker accuracy requires that its tracking accuracy be compared against another tracking system at least as accurate. Comparison against a theodolite array, another identical but autonomously calibrated tracker or some other accurate tracker are the verification options. The verification check should be an on-line comparison, to insure that the results are not weighted in favor of either system.

A good quality microwave tracker is one potential option for a reference tracker. Coverage of the multilateration systems at present is approximately a fifteen nmi radius circle. Assuming the reference tracker can be near centrally located, then it must achieve an angle accuracy of better than 0.2 mr (at 90,000 ft., 0.2 mr corresponds to 18 feet). Compensation must be provided for range and elevation angle errors caused by atmospheric refraction. Refraction can cause errors of tens of feet in range, and over a milliradian in elevation angle. Adequate range accuracy (1 to 2 yards) should be achievable. Care must be taken in calibration to align the tracker properly; i.e., level of "up" (this may include correction to achieve true up if gravity leveling is used) and North. Care also must be taken to avoid solar heating problems (one technique used is to enclose the pedestal within another closed tower) and correct for any other significant error sources. Basically, the required calibration accuracy can only be achieved if meticulous attention to detail is maintained throughout the calibration process. The accuracy achievable with a high quality microwave tracker should be better than 0.2 mr in angle. However, the 0.2 mr accuracy is

of marginal acceptability, 0.05-0.1 mr is a more realistic requirement, since some multilateration system installations may be considerably larger than 15 nmi radius. The post-flight data processing normally employed with the conventional microwave tracker may compromise its utility for on-line calibration use.

A precision laser tracker; e.g., the Sylvania Precision Automatic Tracking System (PATS), also would be a candidate for use as a reference tracker. Its precision can be made more than adequate, such that its accuracy will only depend on how well it is calibrated. Laser radar is not necessarily synonomous with high accuracy. For example, the Sylvania PATS specifications imply an angle accuracy of 0.3 mr for target tracking. However, the narrow beamwidth inherent with laser trackers implies a potential for highly accurate systems, with a side benefit of very good low angle tracking performance. Normally, range performance must be augmented through the use of retro-reflectors on the test/calibration aircraft.

Another option capable of satisfying the requirements for a reference tracker is the on-axis microwave (or laser) radar. Extensive attention to detail in observing errors (including time and time-tagging errors), error modeling and error removal as part of the calibration process is achieved. Accuracy of the order of 0.05 mr has been demonstrated, which has the desired result of making the reference tracker considerably more accurate than the system being calibrated. The on-line (in-loop) data processing used with the on-axis radar yields accurate (corrected) metric tracking data in real time. The current on-axis implementation also has a degree of on-line error observability (accuracy verification) due to the manner in which the boresight telescope is used during tracking. Accuracy of the on-axis tracker can be verified best through comparison with a separate, autonomously calibrated on-axis tracker, either an optical tracker or an identical tracking system. The on-axis trackers should have considerable utility for other range tracking functions when they are not being used for calibration.

A theodolite array can be considered for use as a reference tracker. If photographic data reduction is employed, then it is only useful as an accuracy verification technique; i.e., the reduced data is not timely with respect to calibration needs. An on-line cinetheodolite system would be needed if daily calibration is required.

One also should consider the possibility of extending the self-calibration feature of multilateration systems by giving them the capability to observe their own errors. A possibility for doing this is to use the tracking data generated to drive (point) an accurately calibrated telescope with a video display in the multilateration system control van. This would force improvement in the error modeling until the telescope could be accurately pointed at a target under track. A second telescope is necessary to provide triangulation ranging and facilitate the error observation/error modeling. Switching also could be provided such that the telescope could be selectively pointed at any of the high activity targets under track, thus providing an on-line capability of verifying tracking accuracy during a mission. Note that the telescope is not used like a reference tracker. It is a driven system which provides an accurate observation of angles only (no range information). However, it must be capable of being independently and accurately calibrated, so that it will provide an indication of any error in the data supplied to point it at a target being tracked. It would provide an accuracy indication consistent with the angle resolution of the telescope.

For at least one application; i.e., for air combat training, the multilateration system is not required to have absolute accuracy. Relative accuracy between aircraft is all that is required. This relaxes the calibration requirements for aligning the multilateration coordinate system in a universal sense; i.e., up and North, and for establishing an absolute reference height. One still requires assurance that measurements are accurate within the systems own established coordinate system; i.e., if the relative position between two aircraft must be known to an RMS accuracy of 35 feet, then the RMS accuracy of the position measurement of each aircraft must be about 25 feet relative to the

system coordinates. The calibration problem is approximately the same as discussed above, although if desirable the univeral coordinate system used by the reference tracker or telescope can be transformed to the multilateration coordinate system, or vice versa.

4.6.8.2 Mistiming. (Figure 4-30)

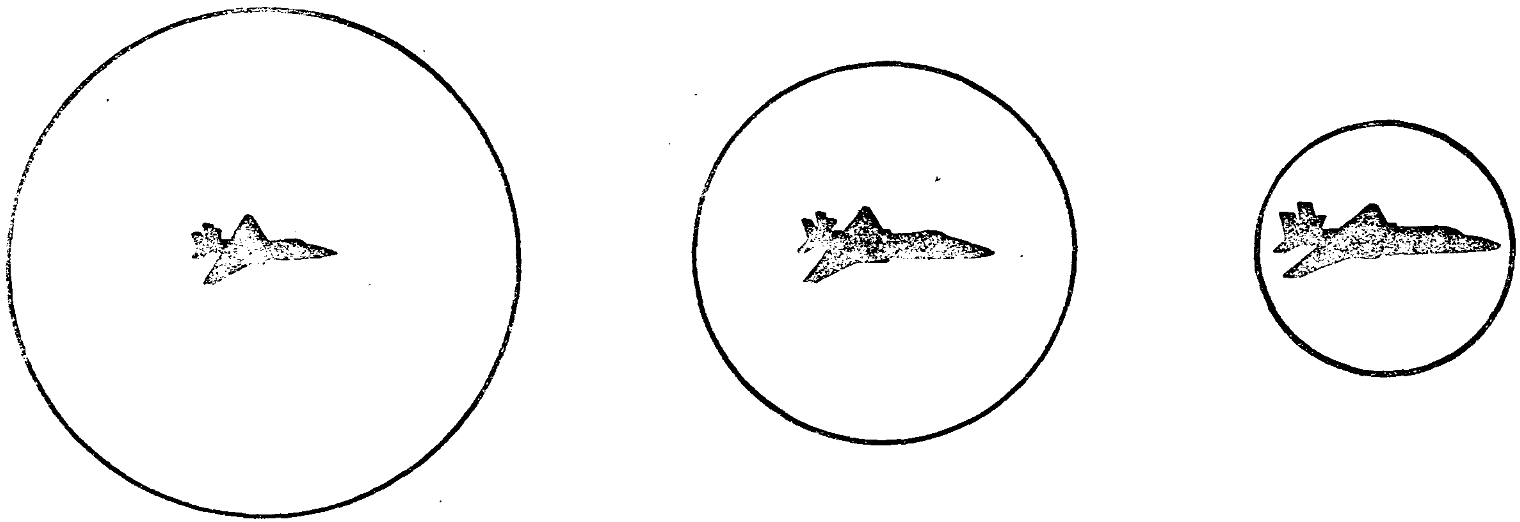
Time must be the independent variable in any trajectory determination process (trajectory = f(time) because, if timing errors exist, all other calibration efforts may be negated. Investigation of trajectory measurement systems has shown that timing associated errors may be the largest single contributor to poor accuracy. An attempt will be made to explain timing errors.

Calibration is the process of discovering, sorting and removing error. Calibration is permitted to improve accuracy. Accuracy is a measure of the closeness to the true value. The ability to produce accurate trajectory data depends on the ability to observe the error process at every step in the trajectory production. A trajectory is defined as a composite vector consisting of position, velocity and acceleration (TPVA) of a vehicle at a given epoch, P, V, A = f(T). If the target is maneuvering in its coordinate frame, then a time sequence of TPVA is necessary to describe its trajectory. The epoch is most often expressed as time of day. It is the accuracy of the derivative data which ultimately describes the accuracy of the trajectory.

It is important that any data to be processed be linear, since most of the processing schemes used for Time-Space-Position Information (TSPI) trajectory measurement, such as least squares filtering, may not function properly with nonlinear data.

TSPI data unfortunately are frequently very nonlinear due to external noise and the data measurement process itself. Therefore, one is much better off if one uses a linear processing scheme. To assure accuracy, it is necessary that the effects of errors in any of the four vectorial components be observable so that the error growth may be controlled.

# MISTIMING
## UNCERTAINTY ABOUT THE TARGET



- TIME OF DAY ERRORS — UNIVERSAL time
- TIME TAGGING — ASSOCIATION OF time WITH POSITION AND DERIVATIVES

SAME —
- TIME FOR POSITION
- TIME FOR VELOCITY
- TIME FOR ACCELERATION

Figure 4-30

Observability is the ability to directly inspect or measure the closeness to the true value. In those cases where piecewise or total observability are not inherent, a measurement system may be improved in accuracy by using an independent device to do the observing for it. Very little observability is present in data processing except in the case of linear systems wherein the superposition principle may be employed.

a. In an electronic distributed sensor such as a multilateration system, observability is practically zero, because of the extensive data processing involved.

b. Observability is medium in a mechanical system which may be pointed, such as radar, until data are processed for correction. During data correction, observability is zero.

c. Observability is high in a mechanical system which is pointed using the trajectory data because the effect of data processing is observable. See In-Loop Integration Control (ILIC), Section 4.6.8.2.9.

4.6.8.2.1 <u>Timing Accuracy</u>

Accurate timing is a necessary part of any trajectory determination operation. All instrumentation must have time available to the instrument to time tag the data. The timing accuracy is determined by the metric accuracy and maximum magnitude of the time-position derivatives experienced in the trajectory measurement process. Velocity is the time-position derivative which generally has the greatest effect on position accuracy, although in some special cases the second derivative may have very large values. Aircraft targets moving at mach II will be observed although there are inventory aircraft which fly faster. Using 2000 ft/second as the aircraft velocity, two aircraft approaching head-on will give a good estimte of the maximum closing velocity of concern. This value is 4000 ft/second. In one millisec ($10^{-3}$) the position uncertainty due to time errors will be 4 feet which is too large if the positional accuracy is to be 10 feet. By using $10^{-4}$ second as the timing accuracy requirement, the target's position uncertainty as relating to time error

will be 0.4 feet, which is an insignificant addition to the error budget. If higher velocities are experienced, then greater timing accuracies are needed. If satellites are to be tracked, the timing in accuracy must be decreased to $10^{-5}$ second because of the increased velocity. Also, if the positional accuracy is significantly greater than 10 feet, greater timing accuracy must be considered.

4.6.8.2.2 Timing Errors

Mistiming is composed of two parts: (1) Time-of-day generation errors and (2) Time-tagging errors; i.e., errors associated with relating time to position and position derivatives for a changing trajectory. Mistiming could be classified as either random or systematic error, however, it is treated here as a third category because timing must truly be the independent variable in the trajectory process.

a. Time-of-Day Errors. A timing error is related to the incorrect time of day or epoch. Generally, time of day is expressed in an Interrange Instrumentation Group (IRIG) format, of which there are several. Timing cannot be assumed accurate, simply by consideration of its format or its resolution. Timing should be checked and evaluated at each local instrumentation site, preferably at the instrument itself. Timing errors are readily observed by comparing the local time as given by the instrument itself. Timing errors are readily observed by comparing the local time as WWV and LORAN C. Using LORAN C, errors in time of day (TOD) processes are easily constrained to $10^{-5}$ second.

b. Time-Tagging Errors. Time-tagging errors are more difficult to detect and remove. Time-tagging errors can be divided into two categories: (1) The coincidence of time with the measured components of position, and (2) The time coincidence with the derivatives of the time-position information; i.e., velocity and acceleration.

c. Time-Position Errors. A single point sensor system, such as a radar, uses a single timing strobe to time correlate the mensuration data, thereby facilitating

time tagging. Other instrumentation systems, such as distributed sensor systems, must use distributed and/or sequential timing to time tag their nonorthogonal components of position. In this case, the noisy orthogonal components of position must be computed, a process not conducive to correct time tagging. Sequential timing significantly complicates the timetagging process. Even when time tagging of position data is correct, the trajectory determination process deteriorates because the position data are noisy. Noisy data require filtering in which an average position and an average time are computed, and this may result in reduced time-tagging accuracy.

d. Time-Position Derivative Errors. By far the largest time errors are related to mistiming of the time-position derivatives. Correct time tagging is important in all applications, but becomes critical if the derivative data are used on-line. On-line processing is accomplished in a continuous fashion such that data are processed and used as they are collected. On-line processing allows for zero interpretation of the data by an analysis, in constrast to off-line processing at some later period. Incorrect time tagging of position derivatives may easily allow the error in using the incorrect derivative data to estimate future epoch velocities and positions to grow with little constraint. Time tagging of velocity and acceleration data from a single point measurement sensor in which all components of position are orthogonal and measured rather than computed is, in itself, complicated. Since differentiation requires use of several position measurements at different epochs, it is difficult to know what time tag should be attached to the computed derivative. The problem of time tagging of derivatives is very much more complicated in the case of a nonorthogonal measurement system from which an orthogonal set must be computed, especially if the nonorthogonal components are measured in sequence rather than at a given epoch. An even more complicated derivative time-tagging problem exists in a distributed sensor wherein all of the time-tagging difficulties are increased by synchronization and transmission problems.

4.6.8.2.3 Universal Time of Day

Prior to January 1972, universal time tagging was subject to irregularities caused by periodic changing of the length of the second to compensate for change in earth rate due to unpredictable and long-term variations. The variable second as the unit of time for precision measurements proved to be unsuitable. On 1 January 1972, the universal time system changed from an earth rotational time system to a constant second system. This coordinated universal time (UTC) is the internationally agreed upon time and is the basis for the time broadcast by WWV, LORAN C and D. Compensation for long-term variations is accomplished by occasionally adding or dropping a second when enough error has accumulated.

Time-of-day generation is broken into three distinct parts: (1) The external synchronization function; (2) A free-running precise frequency standard; and (3) A time code generator.

a. The synchronizing function is done directly with WWV and LORAN C or D or indirectly through range timing. In some installations where LORAN D is not available, a central timing facility distributes a local range timing as the synchronizing source. The precision of the WWV transmitter is 5 x $10^{-4}$ second but, because of nonpredictable propagation anomalies associated with the high frequency portion of the radio spectrum over which it is broadcast, it can only be used to synchronize local clocks to the on-time second. LORAN C or D is of high precision and accuracy ($10^{-6}$ second) at the transmitter site, and because of the predictable low frequency propagation at 100 Kz, the same accuracy is attainable to the receiving station over very great distances. It is not necessary that the synchronizing signal be received continuously, since each instrument should have its own free-running clock which can be synchronized whenever external time is available.

b. A stable high-frequency oscillator, precise to 1 x $10^{-6}$ second is required on site by radars, theodolites, telemetry, etc., as a source for time counting. Generally, this high-frequency time is generated on site, preferably within the instrumentation, rather than by transmission to the site, and must be kept running at all times.

c. A time code generator (TCG), which must also be kept running at all times, correlates the free-running oscillator with the external time source and computes time codes which represent accurate time of day (TOD).

4.6.8.2.5 Star Observation

Trajectory instrumentation frequently has the capability of pointing at the stars for calibration purposes. By pointing at the stars, the local instrument can observe and remove TOD errors. This star evaluation requires a modification of the time of day to UT1 and UT2. UT1 is UTC corrected for the effects of polar axis variation, while UT2 is smoothed UT1 corrected for seasonal variations in the earth's rotation rate. The use of the UTC in lieu of UT2 could result in an error of 13 arc seconds in the star positions used to calibrate the sensor.

4.6.8.2.5 Time-Tagging Calibration

The association of time with measured components of position must be observable at the instrumentation to assure that TOD and the measured parameters are all time coincident. This step in the process is one requiring continuing attention to assure that time coincidence is not lost through routine adjustments and repair of the instrument and/or its recording apparatus.

4.6.8.2.6 Relative Accuracy

Degradation of accuracy in distributed electronic systems may be due to mistiming or position errors. This section emphasizes the mistiming considerations.

Although observability is mandatory in the attainment of accuracy, the standard must be of quality that will insure universality. Universality implies that any other accurate instrument can use the data. By the same token, in a distributed sensor field, a system may have occasional observability, but against a non-universal or internally consistent standard only.

One example of this non-universal standard is two systems (e.g., aircraft pods) flying within a distributed sensor field, with the sensor data as the standard.

(See Section 4.6.8.1.3.3.) These duplicate pods each contain an inertial platform to supply data to the distributed system and are installed on a single aircraft. The distributed ground system produces a trajectory (TPVA) which is used to initialize the inertial data on a periodic basis. The trajectory may be totally divergent as far as universal accuracy is concerned, but can be made to give constrained answers insofar as each pod is concerned if used at a near simultaneous epoch. Even though relative accuracy and, in particular, time-tagging coincidence may be demonstrated by two aircraft flying in formation, this does not assure even relative accuracy, as the two or more targets diverge from a single position. Systems are being engineered in which a single pod is placed on each aircraft, and the results constrained by separately derived trajectories on-line.

Relatively large numbers of targets may be handled in the relative accuracy mode, wherein the timing error is controlled by the on-line reinitialization of all position vectors at near common epochs. Two on-line systems which operate in the relative rather than absolute accuracy mode are the (1) Air Combat Maneuvering Instrumentation (ACMI) and (2) Multiple Airborne Target Trajectory System (MATTS). The ACMI is a multilateration example of the nonuniversal accuracy system, while the MATTS is an electronic angle measuring system employing the same concept and is sometimes called the electronic theodolite system. Another version of multilateration (time of arrival) using distributed electronic sensors is the Range Measurement System/Score (RMS).

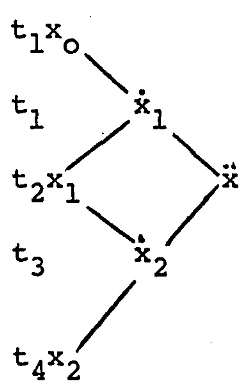
When the data produced by such a distributed sensor system are compared to an external system such as a theodolite, the data are sure to diverge because of the lack of observability in the distributed sensor systems. It is important to realize that, although such a system as described can be made accurate in the universal sense, it is frequently not attempted. The problem is the nonavailability of an <u>on-line</u> standard against which calibration and evaluation may be observed. A conventional radar, either microwave or laser, which requires a post collection error correction process, albeit on line, should be considered with caution because of the low observability in the data correction process. If the data from the radars are corrected off-line, they are not valid calibration standards.

4.6.8.2.7 Optimal Calibrator

A system which may adequately perform the universal calibration function is an In-Loop Integration Control (ILIC) radar, either microwave or laser. It would also be possible to use an ILIC telescope to evaluate the accuracy of a distributed system; however, for an ILIC telescope to be completely adequate from a calibration viewpoint, both systems; i.e., the distributed sensor system and the telescope, must be capable of tracking a satellite, since the range to the satellite may be computed from the angular measurements made by the telescope in lieu of the range measurement made by a radar. Without exception, distributed aperture relative microwave systems require a beacon which is not available in current satellites, therefore, prohibiting distributed systems from tracking satellites. On-line systems should have observability of their own total trajectory data; i.e., TPVA, as a calibration standard. A system should be used which can be checked by driving a remote sensor on-line wherein deviation of the target in the boresight defines system accuracy.

4.6.8.2.8 Post-Flight Process

Since the ordinary sensor can only measure position or its components, some method of determining time-position derivatives must be used. An estimate of the derivatives may be obtained from three time-position measurements by first differences (differentiation) as shown.




where t = time

x = position

$\dot{x}$ = velocity

$\ddot{x}$ = acceleration

Mathematically, instantaneous time-position derivatives can be obtained using the differentiation process and letting the time interval between samples go to zero. In practical measurements, however, one cannot by differentiation calculate the correct instantaneous time-position derivatives in a discrete time system, but rather always derive an average value. In the presence of noisy measurement data, long data spans are required to estimate position and, therefore, the derivatives probably never represent the true value at any epoch. The ability to correctly time tag these derivatives becomes improbable if not impossible, since observability approaches zero.

If target acceleration is constant, this process is valid for determining the average value but, even in this restricted sense, what is the correct time tag associated with this average derivative? The time-position derivatives are always produced after data collection in the derivative process. The situation is in a practical sense worse, since the measurements are noisy, requiring long time intervals for smoothing. If the target is not flying a constant angular velocity around the instrument, the target always accelerates in the frame of the instrument, causing all derivatives to change, thus making it impossible to correctly time tag the derivative computed data.

#### 4.6.8.2.9 In-Loop Integration Control (ILIC) Process

An alternate method of determining a trajectory employs an In-Loop Integration Control (ILIC) process which overcomes many of the difficulties of the post-flight (differentiation) process. Of particular significance is the fact that all time-tagging errors are eliminated. This process starts by using a gross estimate of TPVA dervied by the differentiation process above; a double integration is then performed on the acceleration ($\ddot{x}$) to arrive at a new position ($x_i$). The integration is performed over a very short time interval ($\Delta t$) which assures that the updated TPVA components all occur at the same epoch. Assuming the second derivative (acceleration) is constant for $\Delta t$ (example, $10^{-3}$ second) then:

$$\dot{x}_i = \dot{x}_{i-1} + \Delta t\ddot{x}$$

where $x_i$ = new position

and

$$x_i = x_{i-1} + \Delta t\dot{x}_i + \frac{(\Delta t)^2}{2}\ddot{x}_i$$

$\dot{x}_i$ = new velocity

The sensor (position measure) data are then compared with the calculated position component. If the position is incorrect, the vector is adjusted until it agrees. By this integration process, not only is high observability attained as to the correctness of the total vector, but correct time tagging is achieved.

4.6.8.2.10 Summary

Static timing errors can be removed by observation and comparison with an accurate time broadcast, while care must be taken with dynamic time errors (time tagging) to minimize the effect on trajectory production. Observability of the correctness of the time tagging is achievable through use of the In-Loop Integration Control technique described above.

## 4.7 COMMAND AND CONTROL

Command and Control elements necessary for range safety and efficient direction of activities will vary from simple and austere to complex and costly as a function of the variety of missions to be performed, scored, and recorded. Surveillance and instrumentation radar information must be transmitted and displayed to range operators. Automation of functions will be required to present meaningful information in a format suitable for use.

There are many aspects to range command and control. This section discusses several topics/programs related to command and control, but does not attempt to address the totality of command and control. The following subsections, by title, are:

Range Instrumentation for Control and Scoring (RICS)

Signal Evaluation Analysis and Prediction System (SEAPS)

Frequency Management

Electromagnetic Compatibility (EMC)

Killed Element Removal

4.7.1 Range Instrumentation for Control and Scoring (RICS). (Figure 4-31)

As a result of the considerations contained herein a concept has evolved for a standardized but modular mobile or portable control center for use in range operations at various levels of range centralization. It includes display, communications, and computer facilities for the basic requirement for a control center, which include:

Mission Control
Air Traffic Control
Mission Evaluation
Range Safety and
Environment Management

Incorporation of a modular concept in the RICS design will allow inclusion of Time/Space/Position Information (TSPI) systems in the selected configuration where the required data are not available from associated facilities. For example, a primary and secondary radar for air traffic control and surveillance can be included as well as TSPI systems such as a tracking radar or special scoring systems for the specific missions.

Communications facilities may also be utilized on a modular basis including wire and radio elements for voice, printer, and data communications with associated switching, recorders, etc., as appropriate to the echelon level of the particular RICS installation.

# RANGE INSTRUMENTATION FOR CONTROL & SCORING (RICS)

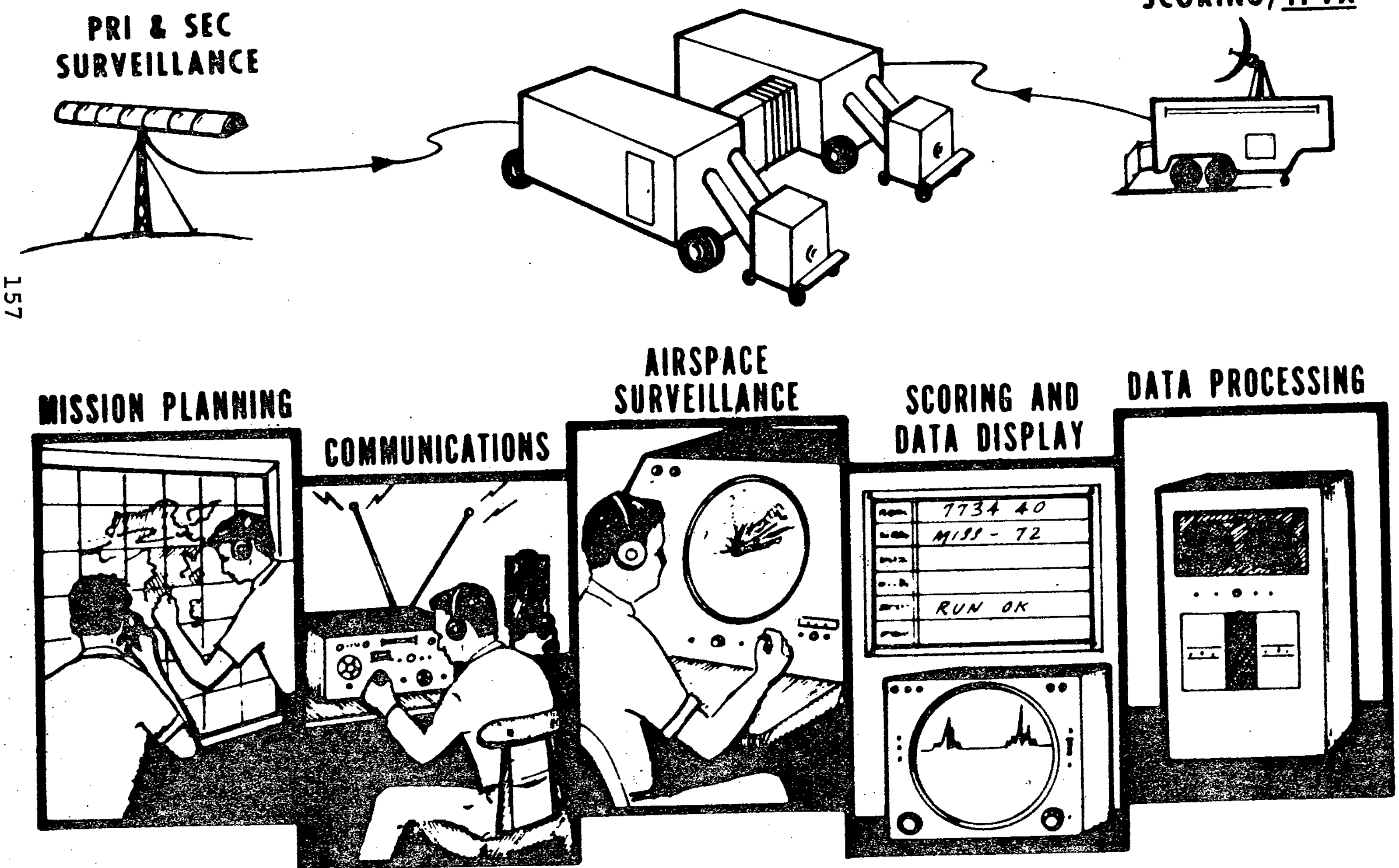



Figure 4-31

Suitable mobile or portable power generator units will be available if required for either primary or secondary use power supply.

The RICS concept has not yet evolved as a definite system configuration, but its usefulness for range operations is evident and its development should be pursued.

4.7.2 Signal Evaluation Analysis and Prediction System (SEAPS). (Figure 4-32)

4.7.2.1 General

a. Effective utilization and training of aircrews in the use of electronic countermeasures equipment in a broad category of USAF Operational Training, Testing and Evaluation (OTT&E) missions have been dependent exclusively upon the resultant effects observed in threat simulator receiving systems.

b. The utilization of electronic warfare equipment, threat simulators, and supporting systems require operation in major portions of the Electromagnetic spectrum also used by numerous non-participating and protected-participant users is severe.

4.7.2.2 Objectives

The objectives of the SEAPS system are: To provide a modular multi-function low-cost receiving/processing system to evaluate aircrews in the use of ECM equipment, and assess the impact of EM activities from the viewpoint of Electromagnetic Compatibility (EMC) and minimum Radio Frequency Interference (RFI) to other spectrum users.

4.7.2.3 System Description

In general the SEAPS operating system would encompass the following modular elements:

a. Premission EMC Analysis. The assessment of proposed EM activity scenarios upon the EM user environment.

# SIGNAL EVALUATION ANALYSIS PREDICTION SYSTEM (SEAPS)

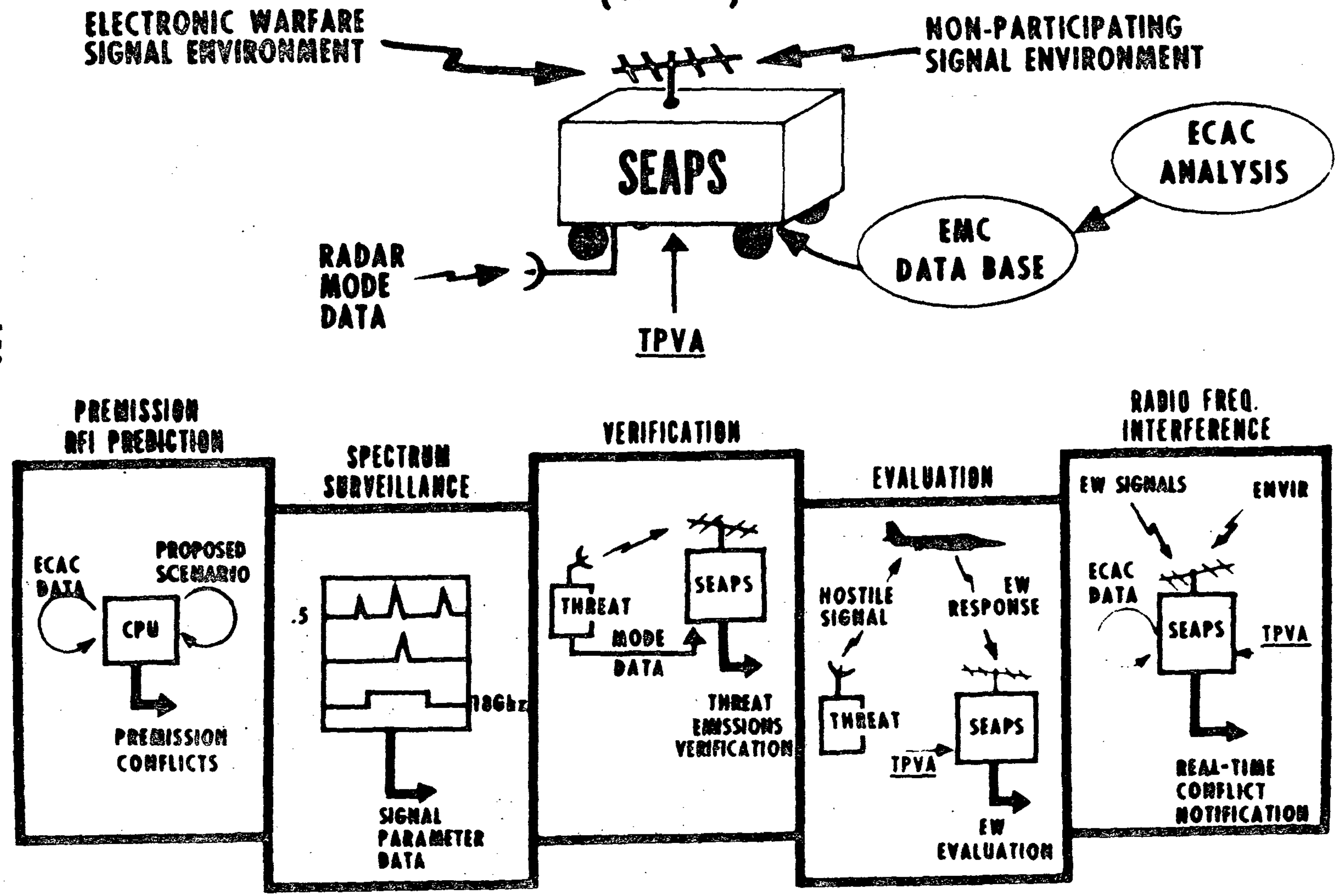



Figure 4-32

b. Spectrum Surveillance. The interception, processing and display of real-time EM environment activities.

c. Emission Validation. The utilization of intercepted signals in the environment from RF emitters (primarily threat radar simulators) to verify that the emissions are valid replications of the threat simulated. This element is primarily a range maintenance function for the threat simulators.

d. Electronic Warfare Scoring. The utilization of Spectrum Surveillance data composed of threat emissions and corresponding aircrew and EW equipment responses to assess the effectiveness of EW activities.

e. Radio Frequency Interference. The utilization of actual Spectrum Surveillance data, emitter locations, susceptible receiver system data and interaction parameters to assess RFI problems and, if required, control EW emission activities.

Figure 4-32 depicts the above operational characteristics of the SEAPS.

4.7.2.4 System Flexibility

From the above description of system capability, several system applications are evident at no additional hardware cost.

a. TEMPEST (COMSEC). The measurement and analysis of signal correlated EM data to ensure TEMPEST security in accordance with NASEM 5106 and 5110.

b. Jammer Management. Utilization of intercepted spectrum data to assess the effects and manage the effectiveness of multiple jammers on radar/communications systems.

c. EMC/EMI Testing. Data collection of spurious radiation spectrum signature data for MIL-STD-449, 461, 462 and 469 purposes.

d. EM Assessment. Utilization of intercepted spectrum activities to assess and notify personnel of RFI from hostile activities to communications and radar

systems and impacts upon command structure. This could include notification of required frequency changes to avoid hostile ECM and the resultant impact to the system operation.

#### 4.7.2.5 Conclusion

The SEAPS will monitor, assess and notify operator personnel of the status of the EM environment to allow optimal execution of USAF OTT&E operations and EW scoring while simultaneously insuring interference-free communications and spectrum usage to non-participant and protected-participant EM users.

### 4.7.3 Frequency Management. (Figure 4-33)

#### 4.7.3.1 General

A principal electromagnetic interference (EMI) control technique available is Frequency Management. Frequency management offices may exercise other control techniques including Time, Location, and Direction Management to ensure electromagnetic compatibility (EMC) of the OTT&E environment.

#### 4.7.3.2 Objectives

The objectives of frequency management programs are to ensure the electromagnetic compatibility of an existing electromagnetic (EM) environment in which OTT&E missions utilize portions of the EM spectrum.

#### 4.7.3.3 Approach

The responsibility for acquiring frequency assignments for military and other government agencies within the Continental US falls upon the frequency control officer in the region in which the OTT&E activity will occur. EMI control options available to the EM planner and frequency control officer in making frequency assignments are presented in Figure 4-33. These options are:

a. Frequency Management

b. Time Management

FREQUENCY MANAGEMENT

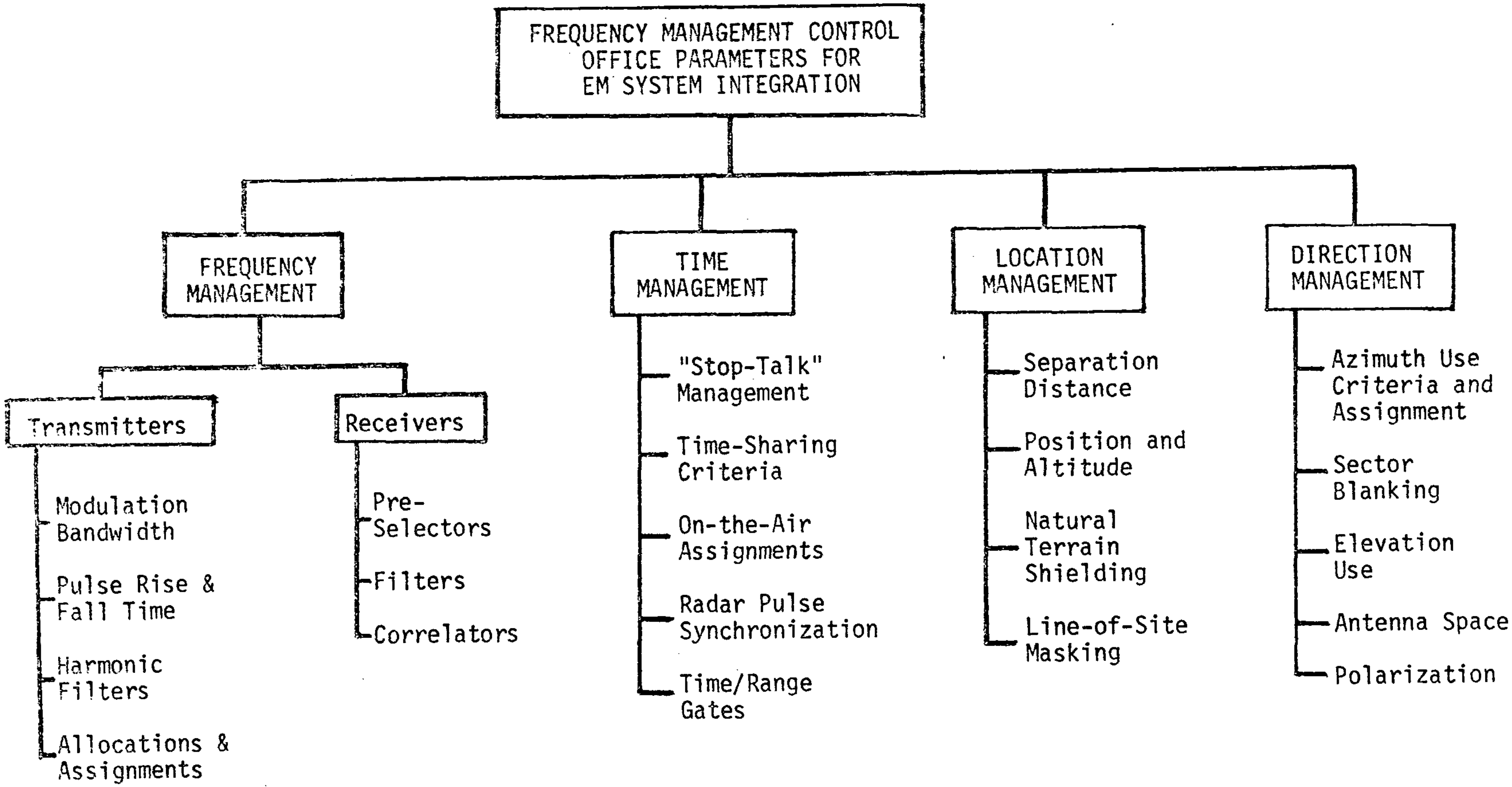



FIGURE 4-33

c. Location Management

d. Direction Management

4.7.3.3.1 Frequency Management

As shown in Figure 4-33 receivers represent the victims of EMI emissions. Since there can be no interference problems without susceptibility of receivers, they must be considered as well as their transmitting counterparts. The objective of emission control is to operationally maintain transmitters so that they occupy the least frequency spectrum possible. RF modulation bandwidth should be no greater than that necessary to accommodate the transmission base-band intelligence.

4.7.3.3.2 Time Scheduling

Time management emphasizes the temporal aspects of EMI control. One aspect of time management is time sharing of one or more frequency bands among several users having different interests. Sometimes this may be achieved on a non-interference basis in which one user has priority during certain hours of the day but other users may also use that band during this period on a not-to-interfere basis. Where two or more radars use the same frequency, a master oscillator or distributed timing sources with LORAN synchronization may be utilized to trigger the radars according to a scheduling plan which will avoid interference among them.

4.7.3.3.3 Location Management

Location management refers to EMI control by the location of a transmitter or victim receiver with respect to other emitters or receivers in the EM environment. If separation and terrain shielding are utilized, significant reduction in EMI is possible.

4.7.3.3.4 Direction Management

Direction management refers to the technique of EMI control by utilizing terrain masking, sector blanking, antenna beamwidth and polarization of EM propagative waves to a receiver system, to reject or minimize interfering transmitter sources.

#### 4.7.3.3.5 Implementation

The EMI control options above may be integrated into one system effort which includes prediction, planning and real-time control. Such a proposed system to assist Frequency Management offices is described in the Signal Evaluation Analysis Prediction System (SEAPS) section of this document.

#### 4.7.3.4 Summary

As the use of the radio frequency spectrum expands, the introduction of OTT&E electromagnetic emission requirements into the environment may create hazardous interference conditions. Options are available in the EMI design, application and EM planning to integrate OTT&E spectrum usage requirements into the existing environment. The successful completion of this integration will be required before any OTT&E missions or equipment procurement would be allowed due to the potential effects upon other spectrum users.

### 4.7.4 Electromagnetic Compatibility (EMC).

#### 4.7.4.1 General

The required compliance of electrical and electronic equipment with electromagnetic interference (EMI) specifications or requirements is intended to assure electromagnetic compatibility (EMC). EMC is the characteristic of equipment and systems to operate as designated without degradation or malfunction in their intended operational electromagnetic (EM) environment or adversely affecting any other equipment or systems. Control and prediction of EMI should take place at the earliest stages possible of the life cycle of equipment or a system as well as in OTT&E mission planning. There are many EMI controls that may be carried out in system and equipment design, deployment and operation.

#### 4.7.4.2 Objectives

The objective of an EMC control program is to ensure that USAF OTT&E programs are executed with minimum scenario restriction and optimum flexibility for the OTT&E participants.

4.7.4.3 Approach

OTT&E programs and missions utilizing communications electronic and weapons systems utilize major portions of the radio frequency spectrum commonly shared by multiple non-participant users. The operational environment of weapons test, electromagnetic countermeasures, and training areas represent one of the most complex EM environments in the world. Three essential phases of an EMC control program are required. These are:

a. EMC analyses.

b. Real-time EMC assessment.

c. Post-mission EMC documentation.

4.7.4.3.1 EMC Analysis

EMC Analysis includes a complete detailed analytical assessment of the proposed EM spectrum activities at the earliest phases of system and operations planning. This assessment may be provided in-house or by the Electromagnetic Compatibility Analysis Center (ECAC). ECAC can provide extensive assessment in all phases of EMC prediction and frequency utilization.

4.7.4.3.2 Real-Time EMC Assessment

Real-time EMC assessments are required due to scenario variations which may be exercised by participants. Pre-mission analysis, predictions and resultant planning are insufficient for achieving complete EMC in an OTT&E environment where optimum EM engagement scenarios are required.

An EMI real-time control program is necessary to detect and solve these problems which will arise, even though not previously exposed by analytical predictions. The capabilities of a real-time EMC analysis and prediction system are further described in Section 4.7.2 of this document.

#### 4.7.4.3.3 Post-Mission EMC Analysis

Post-mission EMC analysis will include documentation of OTT&E EM activities and correlation with range test data. Files update, frequency management booking, EM data base acquisition and interference reports will be required for range documents and a part of post-mission EMC analysis.

### 4.7.4.4 Conclusion

As the use of radio frequency spectrum expands, the need for a comprehensive EMC program for OTT&E users is paramount. Early EMI identification based upon system definition and objectives is essential. The integration between EMC analysis and subsequent EMC management techniques is mandatory to system operation and integration into the existing electromagnetic environment.

## 4.7.5 Killed Element Removal

### 4.7.5.1 Background

In many exercises, simulated weapons deliveries will be scored rather than actual deliveries. These exercises may involve use of electronic countermeasures, including tactical mutual support formations. Continued participation of an element after it has been killed would influence later activities and cause misinterpretation of the results.

### 4.7.5.2 System Description

The evaluation of the effectiveness of the penetrating force during a large scale exercise will depend upon real-time scoring of simulated weapons employed by both sides. When an aircraft or ground element is killed, immediate action must take place to note the event and to reduce the effects of the continued presence of the killed element.

### 4.7.5.3 Alternatives

a. No Element Removal. In some cases the killed element may be left in the scenario for training purposes. This is a valid alternative only if an evaluation is not required.

b. Procedural Removal. In this alternative, the killed element (aircraft) initiates a pre-briefed procedure to exit the exercise area upon notification that it has been killed.

c. Complete Notification. Here, in addition to notifying the killed element of its status, all participants that may be affected are also notified. This includes ground or air units that have been engaging or supporting the killed element. For killed aircraft this will be done by marking the data sent to each threat site for scoring so the killed element can be flagged as no longer participating. At the same time, the killed aircraft should produce a visual indication of its status, such as smoke. This will indicate to other airborne elements and optically directed ground elements, such as AAA units, that the target is killed. Upon notification the killed aircraft will cease all EW activities, and initiate pre-briefed exit procedures. Until a capability for real-time scoring of simulated air-to-ground weapons deliveries is available, it will not be possible to remove killed ground elements. Visual indication of aircraft kill cannot be provided without adding a pod or making some aircraft modification.

d. Other Factors. To maximize training, methods to reinsert killed elements into the exercise in a manner that does not affect the evaluation, must be considered.

## 4.8 COMMUNICATIONS

Communications development must consider electromagnetic compatibility along with a possible need for data encryption. Decentralized versus centralized processing of time, position, velocity and acceleration data will have a significant impact on communications channel and bandwidth needs. Commonality of communication equipment will produce significant reduction in development and acquisition costs and reflect the maintenance and operations training needs.

This section addresses several topics which must be considered in the design of a range communications system, i.e., organization of the data bus for TSPI data transmission, COMSEC and encryption requirements.

### 4.8.1 Data Transmission

A range system is used for the gathering, movement, and production of test data. The data are generally used for evaluation of an external system. Range complexity varies from the relatively simple RBS sites for bombing targets to the very large complexes such as Eglin AFB, Eastern Test Range (ETR) or the satellite control facility network. Many forms of communication are needed for any given range; e.g., target trajectory (TPVA), and identity for the scoring force (White), range $C^3$, housekeeping, threat complex $C^3$, telemetry attacking (Blue) force $C^3$ and external (FAA) range inputs. However, this paper will be specifically directed to a discussion of a concept for handling TSPI data only, since on many ranges it is the major data item.

A common method of implementing a range data system has been to simply connect each instrument to a control center for processing. Normally, this approach came about when the range just grew in function rather than by design. Transmission to a control center requires a high quality (and possibly high bandwidth) full duplex data link from each instrument into a central processor. There are technical reasons for avoiding this which are addressed in Section 4.9.2. Obviously the central processor becomes a funnel through which all data must pass. Often this will cause long time delays in making data available where needed or in making data available after a mission. Critical data processing either may not get done or may have unacceptable delays. A solution to this is to go to distributed processing (as discussed in Section 4.9.2).

This section discusses a TSPI data bus concept which is complementary to the distributed processing concept. With the data bus concept, all instruments and the central processor are tied together through the data bus as illustrated in Figure 4-34. This figure also shows off-range communications going through the central control. This is important to control off-range command/control influences on range operation.

The data bus concept requires a distributed data processing system. Each instrument location, including search radars and IFF as well as the high resolution

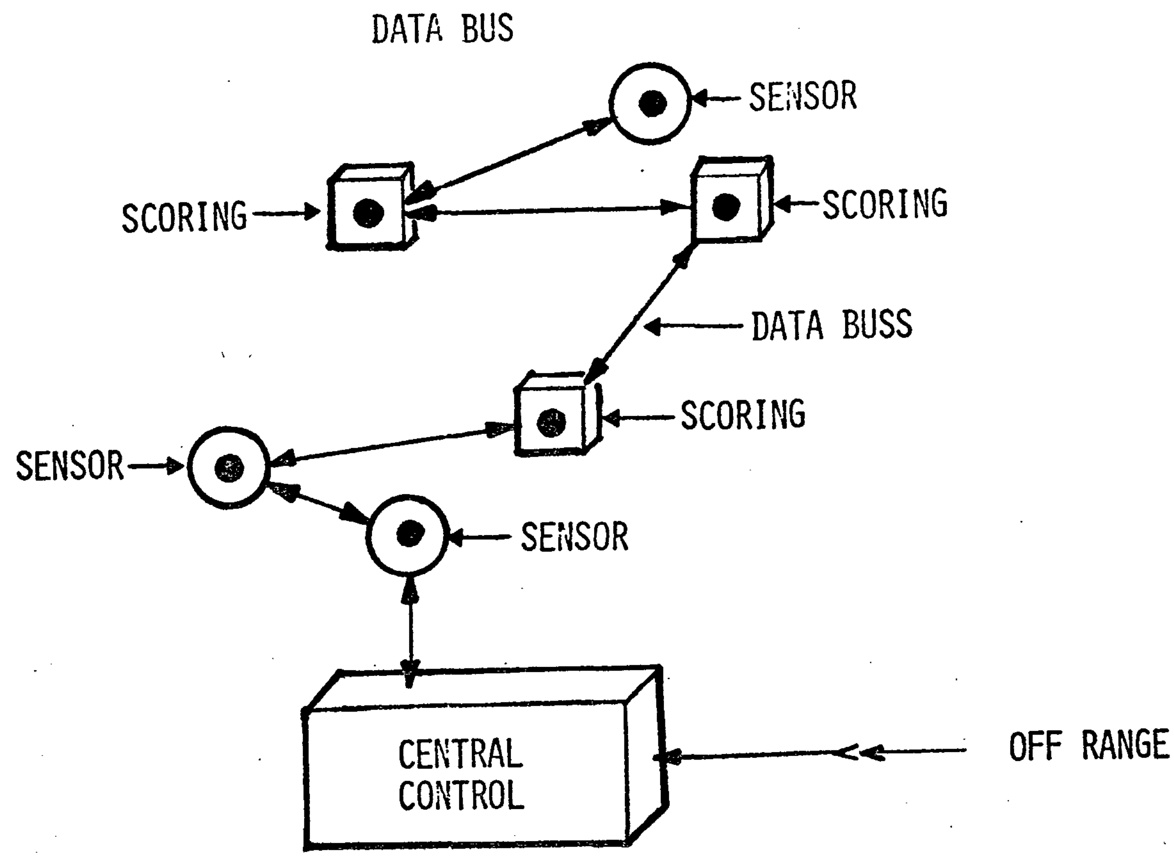

DATA BUS
SENSOR
SCORING
SCORING
DATA BUSS
SCORING
SENSOR
SENSOR
CENTRAL
CONTROL
OFF RANGE

FIGURE 4-34

instruments normally tied into a data bus are required to process their data into a common format and be capable of data comparisons between their data and data on the same target on the data bus. All targets would be assigned an identification number (normally the aircraft tail number) which would remain with the target/participant throughout the mission. The ID number must be assigned by the control center. Each target would have a single data slot on the data bus, even though many instruments may be tracking the target at any given time. A microprocessor (see Section 4.9.2.3) at each instrument would compare any data on the bus with the instrument's own track data on the target. If the instrument data is better, then it is substituted for that on the bus and is immediately available to all other sensors (and central control) on the data bus. Data precision estimates are carried with the data on the bus to facilitate decision making relative to data quality and data substitutions. Good calibration/registration between systems is a prerequisite for successful data bus operation. The data bus, in turn, facilitates the needed calibration/registration because a continuing comparison is possible. The data bus concept requires that data error correction be done on-site to assure registration and be on-line due to the data comparison requirements. Data correction at the instrument is preferable in any case due to there being more information available at the instrument than can be conveniently transmitted to another location.

Calibration validation is facilitated with the data bus. Track data comparison with data on the bus is built in. If the data from the system to be validated agrees with the accurate data on the same target on the data bus, then the system is calibrated. If it does not agree then suitable corrections on-site must be made to yield agreement.

Data Bus Format. The trajectory description of a maneuvering target must include, time, position, velocity and acceleration. If the target is maneuvering then the data rate for updates is a factor. It is expected that TPVA at ten samples/second is adequate to describe the flight path (trajectory of aircraft encountered in today's environment). Of course, if the target is flying straight, level, and not accelerating along its thrust vector, then much lower data rates are possible. The prime consideration is how soon the

system can sense a change from straight and level to a maneuvering mode. If the input sensor is a six rpm IFF, then a maneuver may be detected within thirty seconds. With a tracking radar, a maneuver may be detected at the one-tenth second data rate. The data stream should be made up of multiples of 75 bits/second to insure that the data are excryptable and will normally be 2400 baud. Higher data rates of 4800 and 9600 baud are alternatives. As an example, within each 240-bit TPVA word, time could use 35 bits and resolve one millisec per year. Position use of 26 bits gives a component resolution of one foot, 26 bits for velocity yields a resolution of .5 ft/sec, while 11 bits/component for acceleration gives .5 ft/sec$^2$. Target identity is assigned 12 bits, giving 4906 options and is compatible with IFF/SIF identification. This example would thus use 200 bits for a data word. It is not likely that more stringent resolution requirements will be placed on any one segment than was used for the example. The data should be carried in a universal coordinate system; i.e., geocentric or a subset thereof. (See Section 4.9.1.)

### 4.8.2 Communications Security (COMSEC)

The objectives of a COMSEC program for OTT&E range improvement are to apply the maximum practicable degree of protection to all range telecommunications systems. COMSEC includes the following security elements:

a. Transmission.

b. Cryptographic.

c. Emission.

d. Physical security of COMSEC materials and information.

#### 4.8.2.1 Background

Air Force telecommunications at OTT&E ranges throughout the world are prime targets for foreign intelligence activities and are being exploited to some degree depending upon the susceptibility to intercept, level of encryption, usefulness for intelligence purposes and the information content of data being transmitted.

#### 4.8.2.2 Approach

At this time, total encryption of telecommunications is not practical. However, each command is responsible for identifying encryption requirements and for initiating actions that are necessary to satisfy COMSEC requirements.

#### 4.8.2.3 Recommendations

All telecommunications networks and/or systems used to transmit information of possible intelligence value which is not classified in individual transmissions, but which reveals classified information when collectively compiled and correlated, must be considered for on-line encryption.

Air Force Security Service (AFSS) will provide assistance in determining the sensitivity and vulnerability through test and evaluation (TEMPEST) and recommend a priority for encrypting telecommunications links.

#### 4.8.2.4 Telecommunications Areas

The general telecommunications areas for COMSEC include:

a. Voice communications.

b. Data.

c. Telemetry.

d. Television/Facsimile.

All must be considered as vulnerable elements and analyzed for potential with respect to foreign exploitations whenever they are integral to an Air Force weapons system test.

#### 4.8.2.5 Conclusions

Coordination of COMSEC requirements with AFSS and establishment of a COMSEC education program are essential to communications security objectives. This education program must be designed to relate to the duties and responsibilities associated with the command mission and functional assignments. It must insure that each person recognizes COMSEC objectives and requirements.

### 4.8.3 Encryption

The need for protection from hostile intelligence activities can be partially achieved through encryption of susceptible information transmitted between system elements.

#### 4.8.3.1 Background

In almost every case where encryption is necessary, conflicts of interest arise. A realistic threat environment may be needed to test system hardware yet may reveal intelligence capabilities. System voice communications may indirectly yield test objectives and system capability but require system hardware modifications to incorporate voice encoders. Data transfer systems may require a multitude of user system input/output equipment such that communications and encryption device costs may be prohibitive.

#### 4.8.3.2 Decision Elements

a. Total Encryption. If all communications were encrypted, there would be no capability to incorporate intelligence activities and communications jamming into tests and all of these potential users would be denied use of the system. Aircraft not presently equipped with secure voice communications would require this new capability. This impacts both system configuration and realism.

b. Partial Encryption. Partial encryption of sensitive data systems, evaluation, and operator commentary are presently the most feasible approach to system security. The problems of feasibility and cost are less severe than with total encryption.

c. <u>No Encryption</u>. The most desirable approach to system configuration from the range standpoint would be complete clear text transmission of all data with only minimal or no encryption. This approach allows maximum range realism but compromises system security against hostile exploitation. Some of the exploitation potential may be mitigated, however, by such ploys as using threat data formats similar enough for realism, but different enough to not reveal intelligence capabilities. Considering all aspects of information security versus realism, this approach may prove to be the most practical.

#### 4.8.3.3 Recommendations

In general, the corresponding merits which must be incorporated to provide the capability for system encryption are of benefit to digital systems and costly to analog systems. For example, if TDM/PCM communications modulation techniques are used to provide a bulk encryption capability, modems associated with FM/FDM carrier systems are not required. Voice and analog data transfer are, however, costly in terms of bandwidth requirements for TDM/PCM communications links. If the system is configured to provide on-site evaluations and a central system only providing correlation, analog data transfer should be minimal. Short haul communications could be achieved with hard-line and millimeter communication data links without resorting to encryption.

### 4.9 RANGE SUPPORT

This segment of TT&E range equipment and management covers all support and peripheral areas not included under other specific requirements. Among these are such elements as:

Facilities
Maintenance
Logistics
Operations

Some of the significant special subjects are covered in the subsections which follow.

### 4.9.1 Coordinate Systems. (Figure 4-35)

#### 4.9.1.1 General

The Air Force OT&E and training ranges are characterized by a wide spectrum of capabilities (instrumentation) and geographical extent (land and airspace). Capabilities may vary from little or no instrumentation; e.g., a range for practice bombing runs, to a highly instrumented range complex, possibly consisting of several threat terminal defense areas, air combat arenas, air-to-ground scoring ranges, etc. There can be a corresponding variation in the land and airspace available. For instrumented ranges, one must look at trade-offs and choose a range coordinate system or systems best suited to the range needs. It is the intent here to familiarize the reader with a cross-section of coordinate systems and identify some of the trade-offs involved in coordinate system selection.

A common coordinate system(s) for the interchange of data among a geographically dispersed network of radar and/or other sensor systems constituting the range instrumentation is desirable. A correct selection of a common coordinate system will significantly reduce the bookkeeping required for range command/control, and allow use of data on multiple targets by range sensors as needed. Comparison of data from one sensor with another, as is required for scoring and calibration, is facilitated if a common, appropriate coordinate system is used. But just how much flexibility is available? Threat terminal defense areas, if threat simulators and $C^3$ simulation are involved, will be forced to work in a coordinate system which is at least similar to that used by the defense system being simulated. Range operation inevitably involves an exchange of data with the FAA regional air traffic control (ATC) system. The FAA has an established coordinate system (stereographic) and data format for exchange of data within their own system, with which the range must interface. Nevertheless, a common coordinate system for interchange of tracking data within the range is feasible, although threat system data formating and coordinating system use will be different within the threat $C^3$ structure.

# COORDINATE SYSTEMS
## (ELEVATION OVER AZIMUTH MOUNT EXAMPLE)

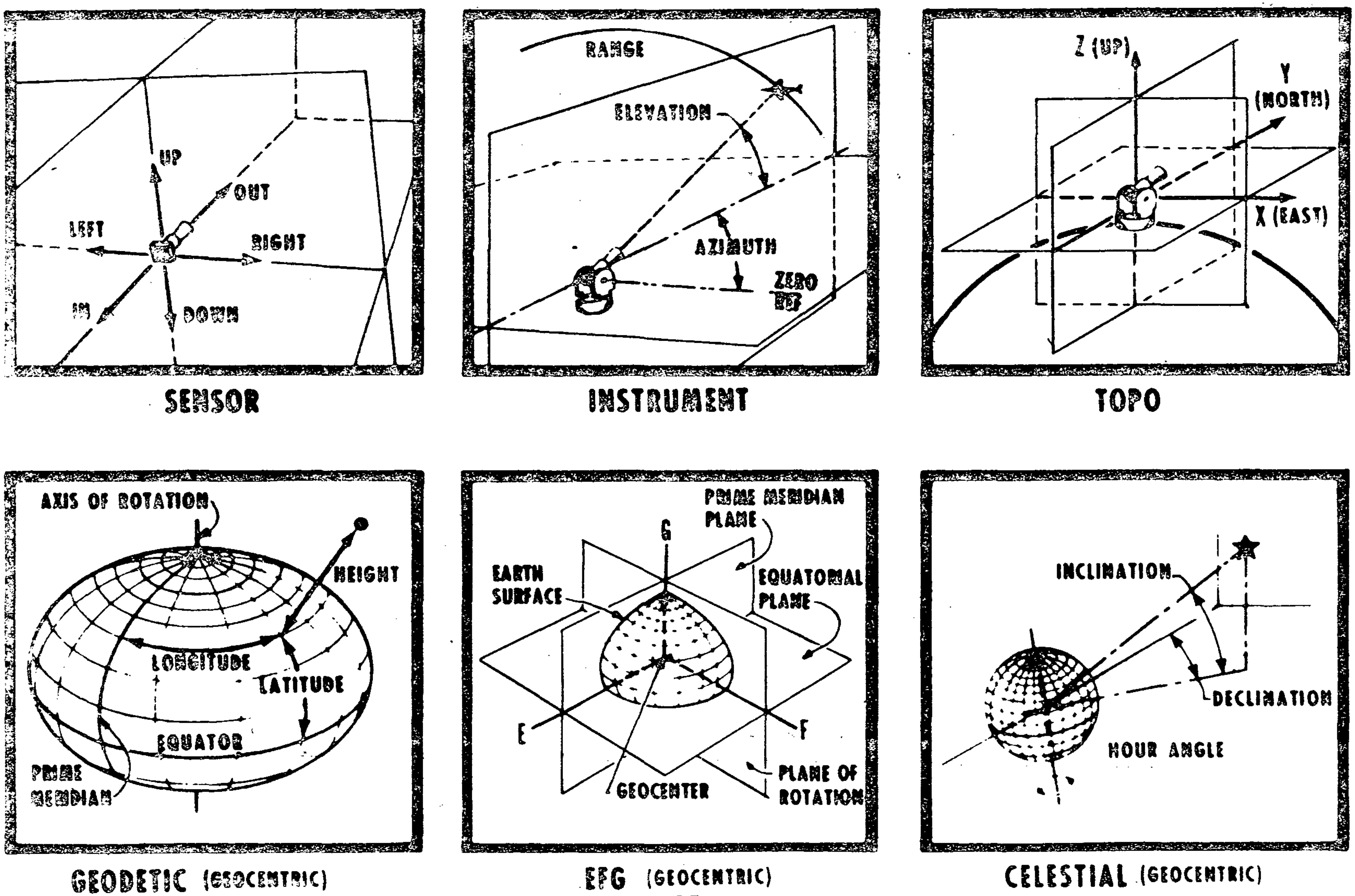



Figure 4-35

Use of a common coordinate system for all data interchange implies a need for a computer (or a transformation "box") at each instrumentation site capable of transforming from the instrument coordinate system to the common range coordinate system and a reverse transformation for data sent to the site. For computational convenience the common coordinate system should be an orthogonal, rectilinear system (Cartesian). Two important aspects which must also be considered are the location of the coordinate system origin and the orientation of the components.

#### 4.9.1.2 Range Coordinate System

Many different coordinate systems will be in use on a test range, extending from several types of sensor coordinate systems to coordinate systems which would have utility for data interchange among instrumentation sites and range control. Figure 4-35 illustrates the spectrum of coordinate systems that may be used by a single instrument, in this case using an azimuth over elevation mount, which utilizes the stars in calibration. Figure 4-36 shows some typical alternatives available for OTT&E use.

The sensor coordinate system is imbedded within the sensor, which is mounted on the instrument. Up-down and left-right associate with the angle sensing portion of the receiver, and in-out with positioning the received pulse within the receiver range gate. Each of the sensor coordinates are then transformed, using range and angle encoders, to the instrument coordinate system--range, azimuth, and elevation (R, A, E). This coordinate system is of little utility for data exchange with other range entities, but is the natural one for use within the instrument. A number of items associated with error correction/calibration and tracking with the instrument must be done in this coordinate system. These include:

- Removal of atmospheric refraction effects (actual computation of the effect involves use of a topospheric model of the earth, not shown in Figure 4-35).

## MULTICOORDINATE SYSTEM USE BY SENSOR SYSTEMS

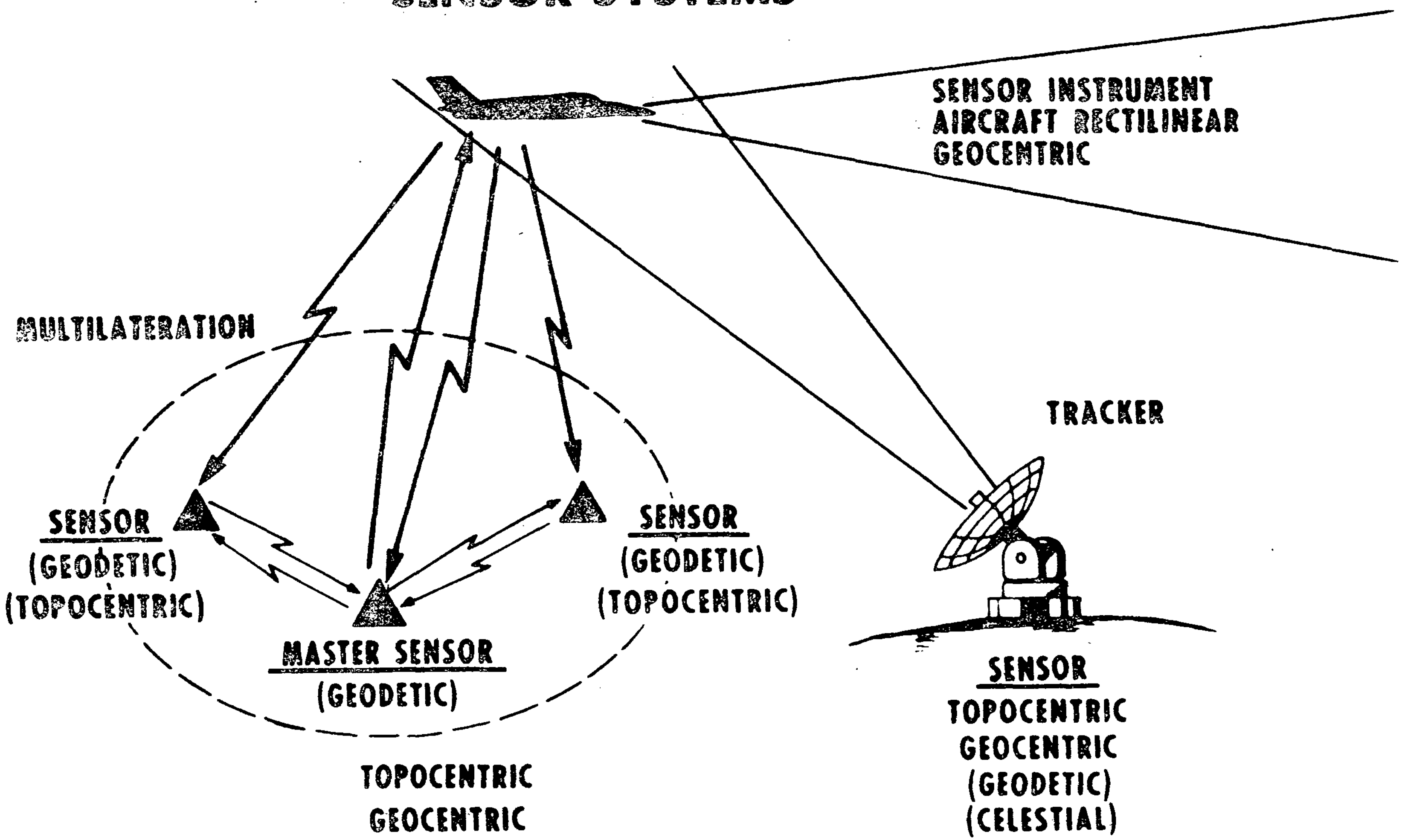



Figure 4-36

- Zero setting of encoders.

- Corrections/additions for non-orthogonality of axes, droop, skew, encoder non-linearity, apparent acceleration, etc.

- Instrument display.

For this example, the data is then transformed to a topocentric, XYZ, coordinate system, centered at the instrument. This references the data to a coordinate system in a form where it can be useful to external users of the data. Information identifying the source of the data and/or the instrument location must accompany the data. For orientation, gravity level is used as a secondary standard for "up," with corrections added on-line to establish agreement with stellar observations. Encoder offsets for North and East are also determined to correctly align the X and Y axes. This coordinate system is convenient for map-type displays.

Three geocentric (earth centered) coordinate systems, each with its own special utility to the instrument also are shown in Figure 4-35: Geodetic, EFG, and Celestial. Geodetic is defined relative to a reference ellipsoid description of the earth and is used to locate points on the earth's surface. The instrument location is determined in a geodetic coordinate system via a survey. Locational components are latitude, longitude, and height (above the reference ellipsoid). Worldwide, there are several different reference ellipsoids in use; e.g., International ellipsoid of 1924, Clarke 1866 spheroid, the Bessel 1941 ellipsoid, Fischer ellipsoid of 1960, and the DOD World Geodetic System of 1966. The survey should indicate which reference ellipsoid was used so that the small differences can be accounted for, if necessary. Three different measures of latitude are defined: geodetic, geocentric, and astonomical. The geodetic latitude (used by survey) at a point on the earth's surface is the angle between the equatorial plane and a line through the point normal to the reference ellipsoid. Similarly, the geocentric latitude (used when pointing at a star) is defined by a line through the point from the earth's center and the astronomical latitude by a line coincident with local gravity at the point.

The EFG is an othogonal, linear, earth centered coordinate system as shown in Figure 4-35. A non-rotating earth is used. The EFG coordinate system is universal in the sense that data users need not be concerned with location parameters of the data generating site. Location and orientation parameters of the using site are all that are needed.

Finally, the celestial coordinate system of Figure 4-35 is necessary to allow calibration on the stars. A rotating earth is used. Star locations, each defined by two angles in this coordinate system, are found in a star catalog (e.g., U.S. Navy FK-4). Appropriate star locations must be mapped back through the coordinate systems; i.e., to EFG, to topocentric, to instrument to sensor, for use in calibration. Note that the sensor coordinate system used in this case is one associated with a boresight telescope mounted on the same instrument; e.g., on the radar elevation trunnion.

Minimal radar implementation allows use of the sensor and instrument (RAE) coordinate systems. Some means of transformation is needed; e.g., a computer or special purpose device, if data mapping to or from other coordinate systems is desired.

Other generic types of position measuring devices will employ a set of coordinate systems suited to their needs. For example, each of the sites in a theodolite array will employ an up-down, left-right sensor coordinate system, which is transformed on site to an instrument azimuth-elevation coordinate system. Computation, normally a combination of manual and computer operations (but sometimes automated on-line) is then used to geometrically solve for position in a topocentric, XYZ coordinate system. Similarly, a multilateration system uses range only data from a number of sites to compute position in an XYZ coordinate system. Note that in our examples, the first common type of coordinate system encountered is the XYZ. In each case discussed, these are local systems with the origin at or within the instrument (for the distributed system, flexibility in locating the coordinate system origin is usually available).

Correctly relating the location and orientation of each instrument to the common coordinate system is imperative. This can be accomplished only if the orientation of each instrument and its location relative to other instrument sites and the coordinate system origin can be accurately determined. This is facilitated if the instrument XYZ system is related to EFG (via a rotation/ translation).

#### 4.9.1.3 Coordinate System Selection Criteria

The coordinate systems of Figure 4-35 are illustrative of the generic types of coordinate systems that might be considered for a common range system. Most are inappropriate for a range system for interchange of tracking data. Data in the instrument coordinate system must be transformed to be useful anywhere other than at the instrument itself. It is possible, however, to transmit data in the instrument coordinate system and do the transformations to some "common" system at the central control facility. Implementation of this approach means that for each instrument, central control must also transform tracking data to be sent to the instrument; e.g., acquisition data or tracking data for scoring, into the instrument coordinate system. Identification of the sending instrument must accompany the data so that the appropriate transformation can be applied. This can be either implicit, if point-to-point dedicated channels are used, or by coding a sender identity in the data stream. This approach puts all of the burden on one or more centrally located computers and operation of any portion of the range will depend on the operational status of this computer and associated communications links. Direct interchange of tracking data between instrumentation sites is not possible if this technique is used.

The geodetic coordinate system is non-linear and is cumbersome for use with tracking data. However, it must be used by the range for all survey locations. The survey location should be transformed into a more convienent, cartesian system for use. The celestial coordinate system cannot be used for trajectory data, since a line orientation rather than a position is defined. It has utility only as an intermediate step for those

instruments which use the stars for calibration. The two options capable of satisfying range needs for a common system are: (1) A Cartesian, geocentric coordinate system; e.g., EFG, and (2) Some version of a topocentric coordinate system, the location and orientation of which are referenced to a geocentric coordinate system.

Two possibilities for a common topocentric coordinate system for display purposes warrant discussion. One is a Cartesian XYZ system, as shown in Figure 4-35 (TOPO) expanded to cover the area of interest. The second is the stereographic, which is widely used by the FAA as a regional coordinate system. Either of these two possibilities allows direct use of the "X, Y" values for map-like display purposes. Map-distortion is present with either system (although at tolerable levels) but is less with the stereographic system. The third dimension, H, in the stereographic representation is defined as height above a curved earth. It is directly relatable to the output of aircraft barometric altimeters without further computation.

A test range can expect a high volume of data exchange with the FAA. This data exchange should be with range control (as should be the case with all non-range entities). Thus, since some other coordinate system is "best" for range use, it would not be unreasonable to have range control do whatever transformations are necessary for data exchange with the FAA. The equations for transformation from a local, instrument XYZ system to stereographic are somewhat more complex than transformation to an expanded XYZ with a different origin.

Transmission of data with either system does not require sender identification.

Although it would not constitute a common range system, use of several XYZ coordinate systems for cases where there are natural subdivisions of the range; e.g., geographically distinct areas, possibly instrumented for different types of test missions, is also a possibility. A separate XYZ system, referenced to a geocentric coordinate system, could be used for each geographically distinct area, with the coordinate system origin somewhere within the area. All tracking instrumentation

within the area would transform to the area XYZ system for data transmission. This transformation is identical to the one necessary to go to the common XYZ discussed above, except that the data word lengths are less due to the smaller area. Data transmissions to range control would require identification of the area of origination of the data, either by coding with the data or by association with dedicated communication channels. Direct interchange of data among sites is possible within the area itself, which is where the primary need exists.

A number of geocentric coordinate systems are in use; e.g., fixed and rotating earth sperical and Cartesian systems, the Keplerian orbital system, and the geodetic and celestial systems already discussed above. There is no need for a rotating earth coordinate system for aircraft test ranges and the computational complexity is a disadvantage of the spherical systems, thus the fixed earth Cartesian system is the likely geocentric system with potential for use as a common range system. The EFG system depicted in Figure 4-35 is recommended as a global (or universal) system for interchange of trajectory data (TPVA) in IRIG 103-69. Thus, if a geocentric system is chosen as the common range system, it should be the EFG system. This would permit interchange of data without further coordinate transformation, assuming that the other ranges also adopt the EFG system.

In the EFG system, each target point is uniquely defined and there is no need to identify the originator of trajectory data, only the user location need be known. The EFG system is designed to accommodate points anywhere around the world. Data expressed in the EFG coordinate System are not directly useful for display purposes and must be transformed to an earth surface system for display use. Word length is greater by four or five bits for each coordinate than is the case for a common XYZ coordinate system.

### 4.9.2 Data Processing

There are many types of sensors/instruments producing data for OTT&E missions. Often these sensors do not produce data which is directly useful and processing is required to convert the data to useful form. This may

be for displays for range control (e.g., target track data, together with alphanumerics and grids/maps), data for frequeny control and management, etc. Data processing is the means whereby raw range data is converted to useful form and/or analyzed.

One example of data processing for filtering, smoothing or prediction is shown in Figure 4-37. Invariably the data measurement process is noisy and processing is required to control or remove the noise. Since the processing is generally non-linear, extreme care must be exercised to assure appropriate answers. Non-linear processing is not well understood and some means of observing or verifying the validity of the processing output is needed. Lack of such observability, except in the use of linear processing, is one of the reasons for the large errors seen in many systems.

Not too long ago, much of the data processing was done using limited function analog devices. In recent years, more and more of the processing has been transferred to digital processors. Digital processors offer a greatly expanded capability, generally at lower cost, and overcome many of the limitations of analog devices, such as drift.

Digital machines have expanded our test capability, particularly for large-scale exercises, but also for small-scale tests. Use of digital processors allows correlation of many events, even when very dissimilar. Use of elaborate display techniques, often allowing flexibility in changing formats, is facilitated. Instruments can be allowed to operate in their natural coordinate systems with the digital devices providing transformations to and from a universal coordinate system for other uses, such as control, without significant round-off errors. Digital processors offer the potential for providing much of the test evaluation on-line while the mission is being run in contrast to collecting large amounts of data for later analysis.

There are pitfalls associated with the greatly expanded capability offered by using digital processors.

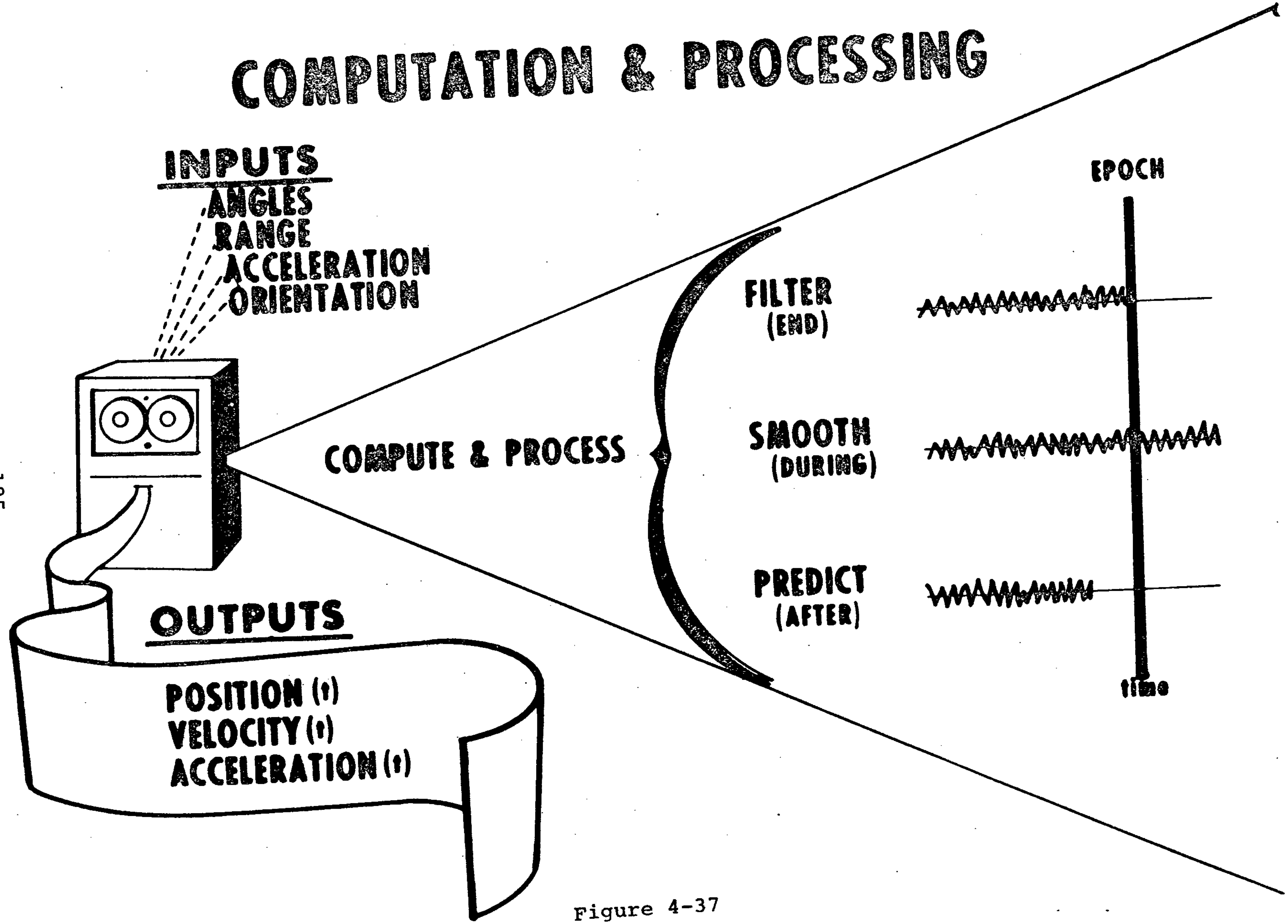

COMPUTATION & PROCESSING
INPUTS
ANGLES
RANGE
ACCELERATION
ORIENTATION
COMPUTE & PROCESS
FILTER
(END)
SMOOTH
(DURING)
PREDICT
(AFTER)
EPOCH
time
OUTPUTS
POSITION (t)
VELOCITY (t)
ACCELERATION (t)

Figure 4-37

There is a tendency for some to believe the output is correct simply because it was produced by a big computer. However, the answers produced can easily be either correct or very wrong. It is up to the user to verify the accuracy of the outputs to avoid drawing wrong conclusions about a test environment or vehicle due to incorrect data. Care must be taken to avoid collecting large amounts of data only to find out later that the data are incorrect and, hence, useless. It is even worse to then use the incorrect data simply because it is all that is available.

#### 4.9.2.1 Validation of Processing

Verification of output accuracy is a serious problem in using digital processors. An approach to solving this problem is to break the process into small pieces that can be checked. Specifically, to move as much of the processing as possible to small, special purpose, single function processors. Input/output relationships can be established for each of the small processors to assist in ensuring the accuracy of the total process. When these small processors are implemented with firmware (see Section 4.9.2.3), the process cannot be changed easily. After verifying the process for correctness, only routine, operational checks need be made.

#### 4.9.2.2 Distributed Processing

This is, of course, advocating a form of distributed processing. There have been large scale attempts to do all range processing in one or more big computers at a central control location. Large software routines governed by a complex executive program are necessary. The executive program alone often takes up a large part of the available memory. In addition, the central processor may over-cycle in the on-line process and incur significant data delays or even bog down. Some of this can be alleviated by moving processes out of the one big machine whenever possible into small, special purpose processors (distributed processing at the central control facility).

A natural extension of this is to move as much of the processing as is practical to the remote sensor locations. It's really a matter of deciding where in the process to logically transfer data between locations. Logically a significant amount of the processing should be done at the remote sensor location, since more information is available there. Data needed by the central processor to provide the control function can then be sent over relatively narrow-band data channels. The data sent would consist primarily of TSPI and result data, such as scoring results. All relevant data should be recorded on site for detailed post-flight review/processing if needed. This approach allows flexibility in terms of future expansion requirements.

4.9.2.3 Microprocessors

Figure 4-38 illustrates a few of the functions which may be performed by special purpose microprocessors to help alleviate the load on the control data processor. Microprocessors can be used to advantage either at central control or the instrument. For reduced scale operation, all of the control processing may be done at the instrument.

Recent developments with microprocessors have reversed the process of building bigger and more complicated digital data processors. When much of the data processing was analog, usually each function was accomplished in a unit designed for a specific operation. As digital computers were developed, more and more functions were done in the computer with increasing reliance on software programming. It is now possible, using microprocessors, to again do many of the processes with units designed for the specific operations. This type of non-programmable, digital hardware is called firmware. Its use allows the design engineer to again do total system design rather than turning large parts of it over to the software programmer. It has become easy to use digital firmware and easy to change the firmware if the right equipment is available. Computers have become faster, and effectively larger, because many of the functions previously done in software are now done in

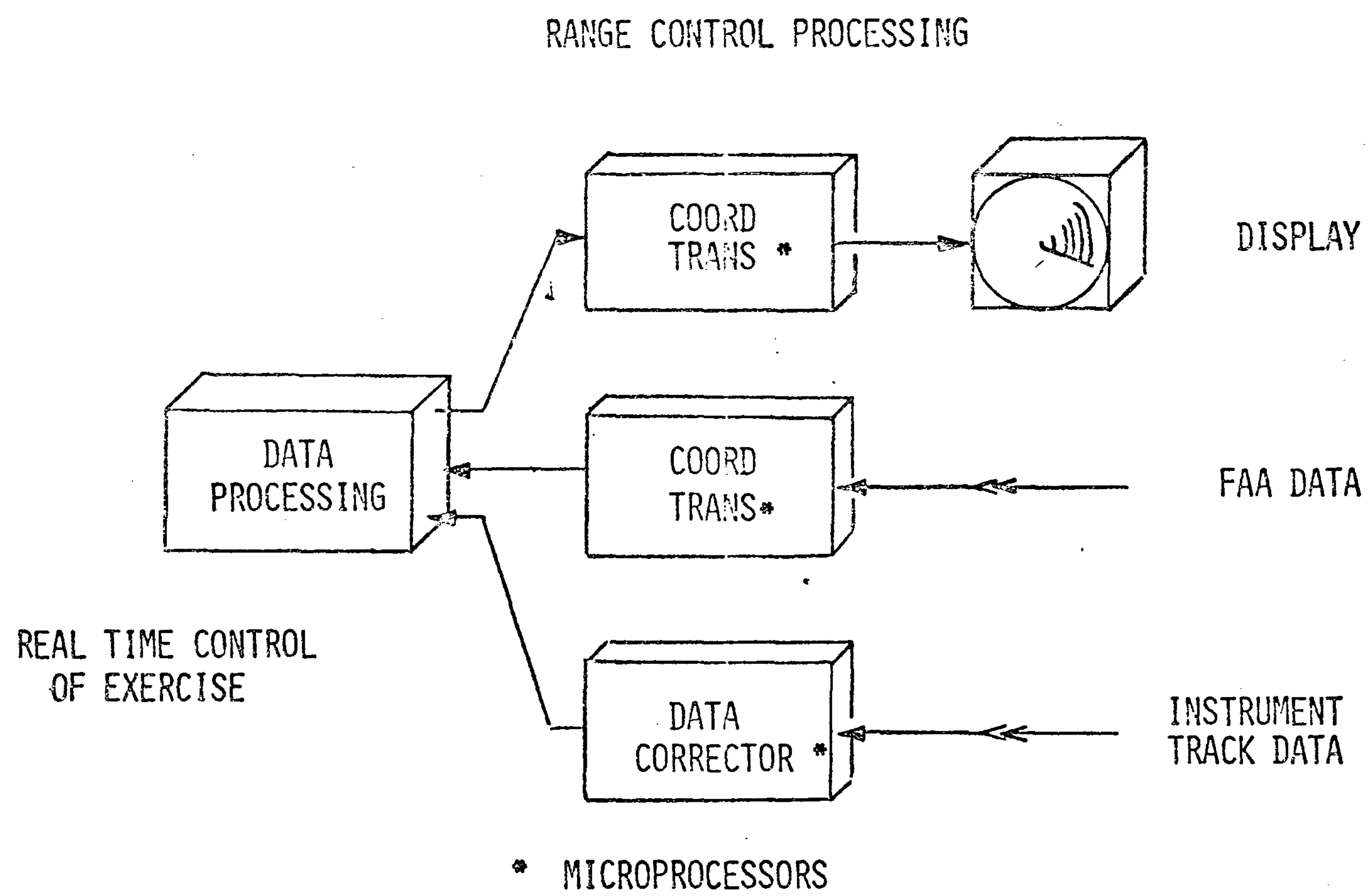

RANGE CONTROL PROCESSING
COORD TRANS *
DISPLAY
DATA PROCESSING
COORD TRANS*
FAA DATA
REAL TIME CONTROL OF EXERCISE
DATA CORRECTOR *
INSTRUMENT TRACK DATA
* MICROPROCESSORS

FIGURE 4-38

peripheral firmware devices. Any well defined process can and should be done by a microprocessor, leaving only the less well-defined processes to be accomplished via software. Firmware devices are small, low cost and are not readily changeable in the field without special equipment. Their use helps make each piece of the process functionally checkable, thus making it easier for the user to validate results. Many non-iterative processes do not require the power of a microprocessor and should be done with the hardware cards.

Figures 4-39, 4-40, and 4-41 show special purpose microprocessor cards for processor, memory and program storage modules. These are fairly elaborate relative to the needs of many of the functions mentioned. However, they can be made more or less complex as required.

Some functions, particularly for large scale exercises, are still best done in a central processor. These include total system testing, system status, kill removal, test planning, any required post flight analysis and on-line exercise control functions.

### 4.9.3 Displays

One of the primary uses of displays is for rapid, composite communication between man and machine. Displays have come to be a vehicle for the user to observe missions in detail, on-line or soon after, without waiting for computer processing and print-outs. Often a display may include more information than can easily be assimilated in real-time and the user may want to selectively play back portions for reviewing. A common type of display is a map-like display showing aircraft position. For some uses it may be desirable to also have the map-like display show range boundaries, geographical features, ordnance footprints (for safety decisions), alphanumerics to augment target positional information, expected flight paths or other information of interest to a particular user. Other displays may be needed for such things as equipment status or to display expected versus actual electromagnetic radiation for the spectrum management and control officer. There are many other

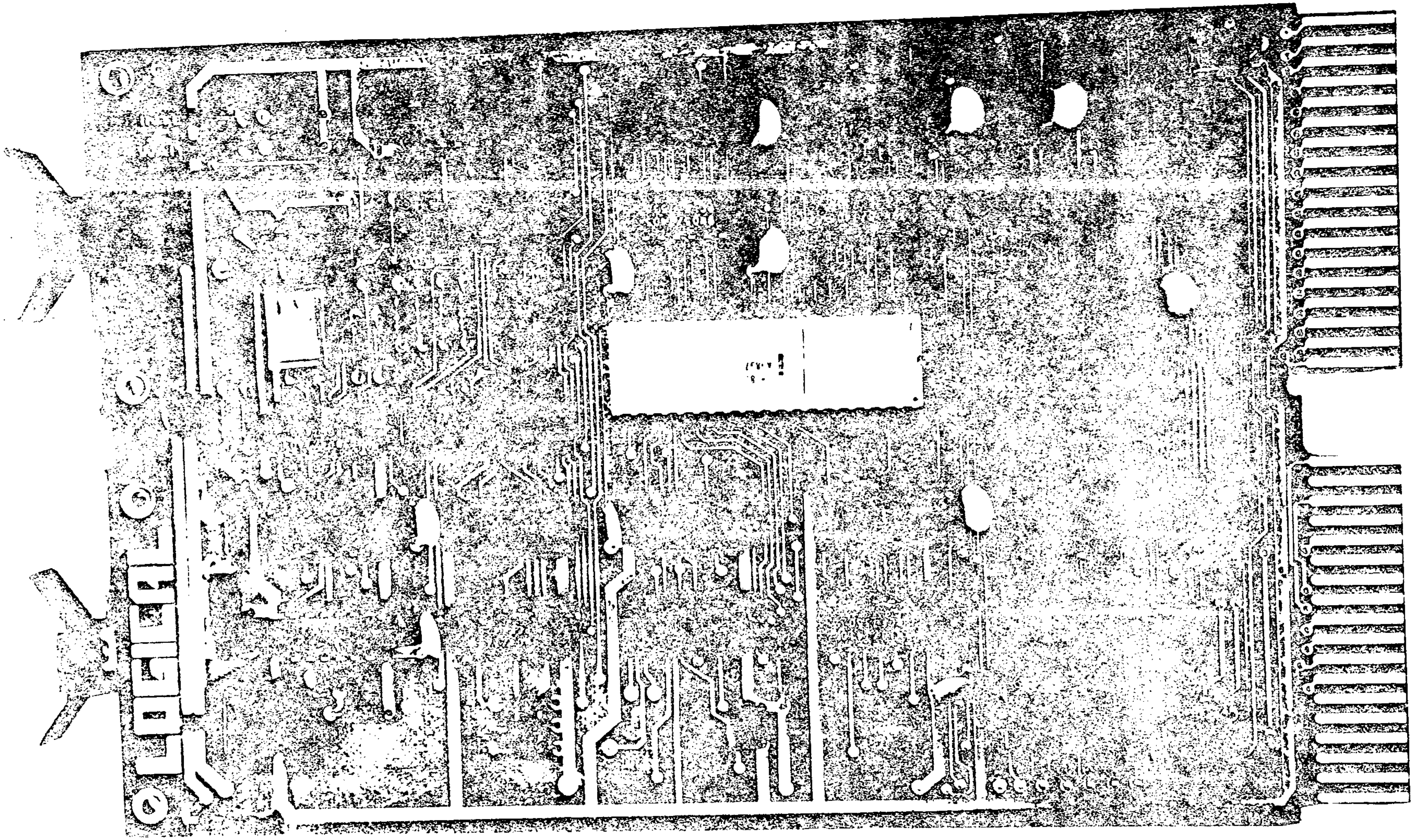


FIGURE 4-39

**PROCESSOR MODULE**

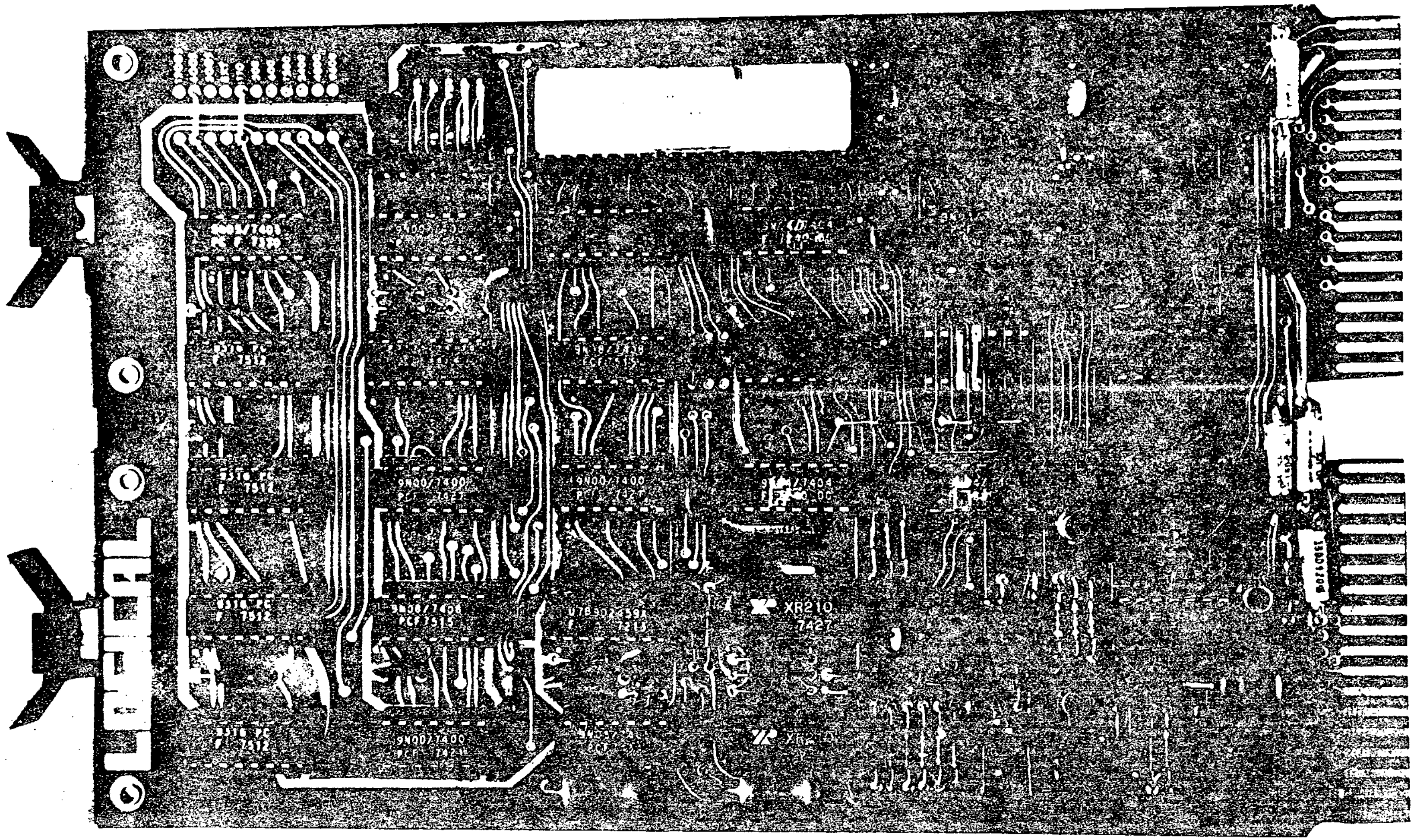



FIGURE 4-40

RCU-100/520 MEMORY MODULE

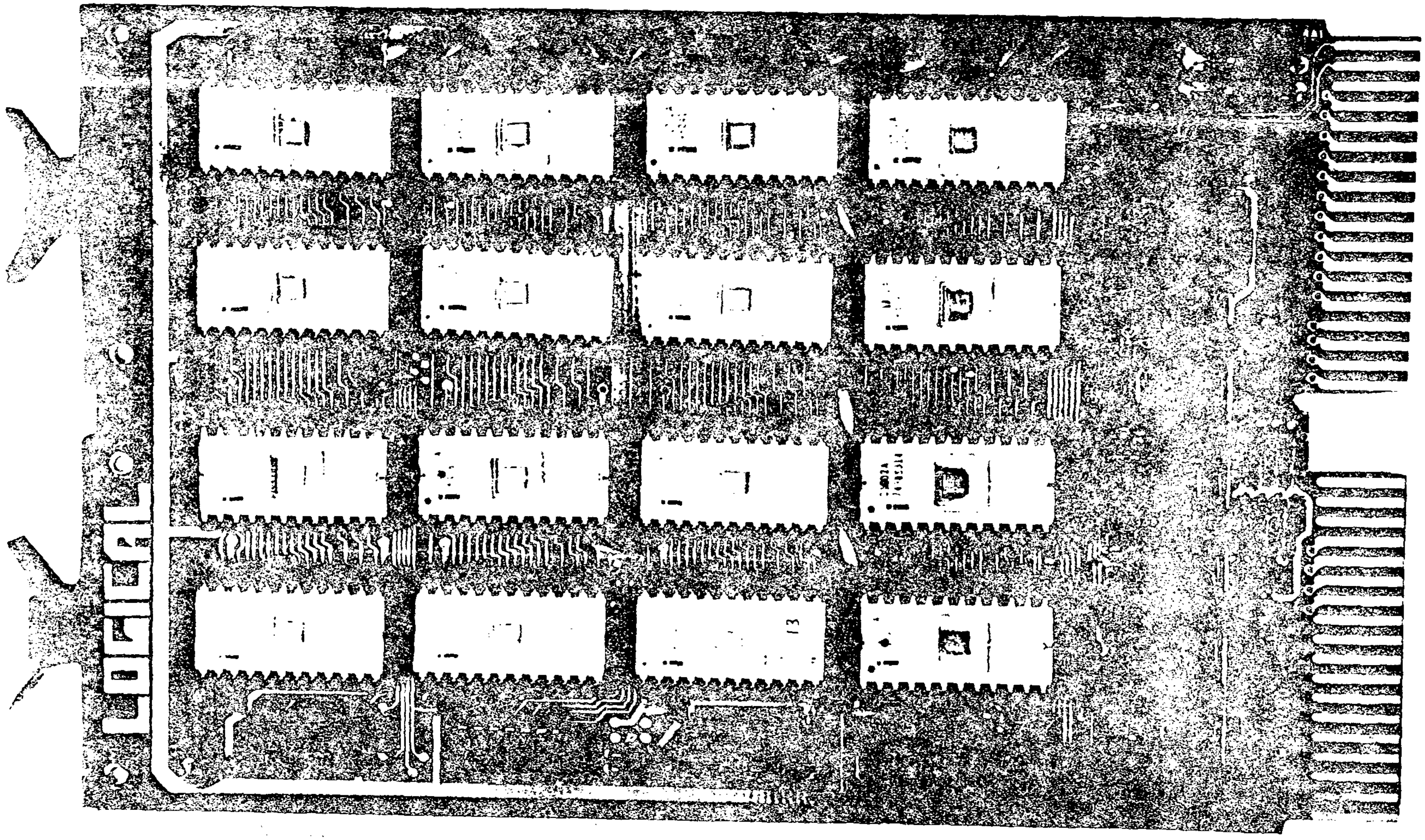



FIGURE 4-41

**RCU-100/530**
**PROGRAM STORAGE MODULE**

possible display requirements. Proper use of displays is important to progress towards achieving a real-time range capability. Much, if not all, of the display information must be recorded, partly for user mission review for more complete assimilation of information, but also in case of failures or accidents.

There are a large number of display options available to the range designer. Chosen displays should show all of the data needed to functionally evaluate or control the process of concern and should meet operational as well as analytical needs. More data than is critical to the mission itself should be displayed, e.g., calibration data, etc., with the mission critical data being emphasized by using color or flashing or some other technique. Use of computer driven displays, with the capability to change data and/or format at user command, yields considerable flexibility and may allow a reduction in the number of displays.

Requirements for record/playback should help dictate the selection of display itself should impose minimal special requirements on playback equipment, e.g., use of standard 525 line TV recording allows playback at any location without special equipment.

For a given application the type of display needed will be partly dictated by the type of data. The data may be either digital, such as TSPI data, or analog, e.g., radar video or optical boresight TV video. The selection of electronic display types available include roster scan TV, direct driven cathode ray tubes, alphanumeric, etc. Mechanical or manual plotting boards are also still in use. Record and playback dictates the use of electronic displays. Reconstruction of a mission via playback requires that data as well as video be recorded. Alphanumerics can be added easily to a TV display for both on-line and playback use. Direct driven cathode ray tube displays are well adapted to digital data and/or graphics, but not to analog data. Any of the electronic displays can be remoted if desired. To the extent that they are computer (or microprocessor) driven, there can be great flexibility in changing data and/or format in accordance with user commands.

TSPI (target trajectory/TPVA) displays utilize digital data and a direct driven cathode display can be used. For some applications this data will be displayed as a map-like display with alphanumerics included to provide identification, height, direction of movement, velocity, etc. Maps or geographics may be overlayed. The display projection can be anything desired, e.g. Mercator, stereographic (as used by FAA) or a polar version (as used with a PPI). Three dimensional displays are also possible, with the view angle and perspective scaling accomplished by a microprocessor in accordance with operator commands. Recording of these types of displays can be done using a scan conversion to a roster scan for play back on standard television equipment.

#### 4.9.4 Flight Simulators

The usefulness of flight simulators as a technique for enhancing aircrew training is well established and documented in the June 1974 edition of the "Air Force Master Plan, Simulators for Aircrew Training", ASD/XR Report Number 74-22. The energy shortage, the escalating costs of aircraft procurement and operation, and the need to extend the life of operational aircraft emphasizes the requirement to accelerate improved simulator capabilities and expanded utilization in order to reduce actual flight time requirements with their associated costs. The present Air Force master plan for simulators covers the aircrews training problem quite adequately. However, the use of simulators as an adjunct to operational testing is not addressed. The following discussion covers the potential exploitation of existing and programmed flight simulators to enhance operational testing and evaluation.

##### 4.9.4.1 Flight Simulators Technology

This section addresses flight simulation technology. Areas covered are as follows:

- current technology
- functional systems
- development areas

### 4.9.4.2 Current Technology

Flight simulator technology falls into three basic areas; Cockpit instrumentation, Motion, and Visual. The capability to accurately simulate cockpit layouts, the operation of basic flight instruments, avionics, radar etc. has been well established for some time. Current versions of simulators for the F4 and A7 aircraft provide very good instrument simulation.

Motion simulation continues as an area of considerable debate. Numerous studies have been performed which strongly support the position that motion is required to provide necessary, meaningful cues to the pilot.

State of the art motion systems provide relatively large amplitude excursions with six degrees of freedom. A relatively new development in this area is the G-seat--a cockpit seat lined with air bellows which are differentially inflated to exert pressures on the body which correlate to those experienced in flight by gravity forces. The use of a G-seat is usually combined with a G-suit worn by the pilot.

It should be noted that motion systems represent finite size and weight limitations on simulation hardware.

Visual simulation continues as the most difficult of the flight simulation technologies; it has the most problem areas and is the subject of considerable ongoing development effort.

Virtually all simulators available today are regarded as part task trainers--this designation is governed primarily by limitations of the visual system. On a given simulator, only a limited number of visual tasks, can currently be simulated and normally only one major area (air-to-air combat--air-to-ground weapons delivery, takeoff and landing, night landing, etc.) can be simulated well. Users are currently demanding full mission simulators which are capable of doing all things using a single cockpit. This capability is not currently within the state of the art.

Numerous cockpit displays have been developed and are in common use now which differ considerably in terms of both performance and cost. Display fields of view range from approximately 60 degrees (CRT driven mirror beamsplitter used for takeoff and landing simulation--ceamsplitter used for takeoff and landing simulation) to angles which virtually duplicate the available field of view from our most modern fighter aircraft. Both real image and infinity image (virtual image) displays are in use. Color systems have been built having fields of view up to 120 degrees. However, color systems currently suffer from lack of detail resolution which can be provided by monochrome systems.

Three sources are commonly in use today for inputs to the visual system. Models (of terrain or target aircraft imagery) are the most common visual image source. Some systems currently use computer generated imagery (CGI). However, current CGI imagery tends to apear somewhat cartoonish). Several systems have been built in the past which use film (large plates or strip film) for the image source. A common limitation of all such image sources is the gaming area available.

4.9.4.3 Functional Systems

a. Simulator for Air to Air Combat (SAAC). The simulator for air to air combat is probably one of the best examples of the application of current technology in all areas. This simulator features two cockpits, each on six post motion systems, each simulating the F-4 aircraft. Each cockpit has a full instrument panel with functional radio aids, radar, and a lead computing optical site. G-seat and G-suits are available in each cockpit to supplement the six degree of freedom motion system. Each cockpit is equipped with a visual system which has a field of view equivalent to that available from the real aircraft. The display is comprised of eight cathode ray tube image inputs which are merged and focused at infinity by an optical package called a pancake window. The system displays a sky, horizon, checkerboard ground terrain, and a high resolution image of another aircraft. For each cockpit, the other aircraft represents the adjacent simulator cockpit; its range, attitude, location, etc., controlled

by the flight of the adjacent cockpit. The two cockpits are linked by a sophisticated computer system. This simulator was the product of an advanced development program at ASD. The hardware was built by Singer Simulation Products Division located in Binghanton, NY. The hardware is now located at Luke AFB.

b. Advanced Simulator for Undergraduate Pilot (ASUPT). The ASUPT simulator is a dual cockpit device developed for simulation of formation flight in the T-37 aircraft. It features two cockpits having CRT/Pancake window monochrome display systems which are similar to those of the SAAC system except that the ASUPT displays are larger. The simulator cockpits feature full cockpit instrumentation for the T-37B, and six post, six degree of freedom motion systems. The imagery presented by the display is computer generated and is limited to that which can be created with 2000 edges. Imagery presented to the pilot includes a formation T-37's, airfield, runway, and generalized terrain areas.

c. Large Amplitude Motion Advanced Research Simulator (LAMARS). The LAMARS simulator is a single cockpit device which incorporates a wide field view dome type visual display. The twenty foot diameter dome viewed by the pilot from the cockpit located inside the dome displays a featureless sky, featureless terrain, horizon and a high resolution target aircraft image. All imagery is real--projected on the dome surface. The target aircraft projector may also be used to project an air-to-ground image having a sixty degree field of view. This area can then be used as an Area of Interest (AOI) which is moved about the total field of view of the display. The motion system for LAMARS simulator is unique--the twenty foot diameter dome is located on the end of a long boom and servoed such that five degrees of motion are available. Wide excursions for lateral and vertical motion are available. Cockpit instrumentation in this system is limited to that of a generalized aircraft. This simulator was built by Northrop and is currently in operation at Wright-Patterson Air Force Base by the Flight Dynamics Laboratory.

d. MACS III. MACS III is a dual cockpit air-to-air combat simulator operated by the McDonnell-Douglas Aircraft Corporation. The system features two fixed base (no motion) 40 foot domes onto which are projected a featureless sky, terrain, horizon, and two simultaneous target aircraft images. The system is also capable of displaying a projected sixty degree field of view color ground terrain image which can be slewed about a limited area of the field of view.

e. F-4E No. 18. F-4E simulator number 18 features a visual system developed for air-to-ground weapons delivery. The system consists of an F-4 cockpit with a six post motion system and a color visual display having a field of view of approximately 120 degrees. The cockpit display is comprised of six high resolution color television picture tubes which are combined and focused at infinity by mirror-beamsplitter optics. Imagery for the visual system is taken from a terrain model board. This system was an attempt to incorporate numerous advanced subsystem elements. Difficulties were encountered, primarily in the area of the optical probe (lens) used with the television camera which viewed the terrain model board. The current system is limited by low image resolution presented to the pilot caused by the integration of several marginal components. The gaming area of the terrain model is also regarded as inadequate for the air-to-ground task for which the system was conceived.

f. Simulator for Electronic Warfare Training (SEWT). The SEWT simulator is not a flight simulator; however, based on its applicability to range simulation it warrants mention here. The SEWT is a multi-student station ground based training system controlled by a common computer. Each student station includes a collection of navigation and electronic warfare equipment as required to simulate the EW package used for the B-52 and Wild Weasel systems. Students are presented with threats which are assigned by the instructor. The student's performance in defense of the threat is scored based on a criteria established by the instructor.

#### 4.9.4.4 Development Areas

As you might well expect, most ongoing simulator technology development is directed toward the visual

area. Requirements for full mission simulation, wider fields of view, color and higher resolution all drive development efforts in these areas. Efforts are also underway to develop the capability to simulate airborne sensors (forward looking infrared, TISEO, Low Light Level Television/LLLTV, etc.). Most current approaches to this problem use terrain model boards viewed by television cameras. Current systems such as the Simulator for Air-to-Air Combat can be reprogrammed to simulate the flight characteristics of other aircraft. Weapon firing trajectories can be calculated and hit scoring system developed within existing technology. Simulation of land and air based radar systems is within the existing technology. Simulation, as it exists today, may be highly applicable to the range pretest task, and may also be considered as an alternative to the use of flight test ranges and aircraft for some test programs.

4.9.4.5 Relationship of Simulators to Live Testing

As outlined in the previous section, the inventory of available simulators is continually expanding. There are a number of simulators for Flight training associated with particular types of aircraft, a new simulator for air combat (SAAC), and a new simulator for Electronic Warfare (SEWT). There are also other simulators which could possibly be made available for tests and evaluations, such as the NASA Dual Maneuvering Air Combat Simulator at Langley, Virginia, the Electronic Warfare Environment Simulator (EWES) at General Dynamics, Fort Worth, Texas, and REDCAP Electronic Warfare Simulator at Calspan in Buffalo, New York.

It is worthwhile to note that the failure to properly exploit the interrelationship between simulations and operational testing has been noted and lamented by a number of prominent Defense organizations and boards. These include the USAF Scientific Advisory Board in 1966, the Blue Ribbon Defense Panel in 1970, a MITRE study of OTT&E "Lessons Learned" in 1971 and most recently in a review of test and evaluation conducted for DDR&E by the Defense Science Board in 1974.

4.9.4.6 Simulator/Live Test Interrelationships

How can simulators be used to aid the design of live operational tests? Here is a list of some of the more obvious techniques.

- Use of Simulators to Aid Live OT&E Test Design

  - Determining sensitivity to instrumentation errors.

  - Exploring effects of unavoidable live-test unrealities.

  - Identifying areas of greatest information return and most important variables.

  - Developing models for effects of uncontrollable variables.

  - Estimating the variance of results.

This list is certainly not exhaustive, but illustrates some of these points by reference to Air Combat Testing. Simulators can be used to determine the sensitivity of the results to instrumentation errors; to answer the question, "If our instrumentation is poor, to what extent will that jeopardize the credibility of the results?"

4.9.4.7 Sensitivity to Instrumentation Errors

With respect to Air Combat testing, the ACMI, which is currently being acquired, may not have sufficient accuracy to warrant the simulation of gunfire trajectories, or for that matter, the rather detailed multiple-target acquisition and resolution problem which is intended to be incorporated in the missile simulations. One could certainly use a simulator to check a few situations, one-on-one and two-on-one, in which an exercise would be simulated and the results tabulated if there is: 1) No error in instrumentation, and 2) When the positional data and attitude data is degraded with errors, first with errors which are inside the specified

accuracy limits of the ACMI, and secondly, if the errors in Z (vertical component of position) and in attitude are further degraded outside specification for ACMI, as some preliminary indications suggest that they may be. The results of this direct comparison of the same setup with and without errors can answer that question -- "Will the inaccuracies of the ACMI jeopardize the credibility of the live test results or not?"

#### 4.9.4.8 Effects of Unavoidable Live Test Realities

Another use of a simulator in the planning for live test is to explore the effects of the unavoidable unrealities of the real test. Because of safety constraints, no live missiles or live gunfire are used in the current testing. What this means is that there will be no visual cues of any missiles in flight provided either to the attacker or the target, and there will be no tracers provided to help a pilot to correct the trajectory of his gunfire. It might be argued that these cues are unimportant and therefore the live tests will not be jeopardized by the absence of these cues. Whether it is important or not must be conjecture until it has been tested. One place to test such a hypothesis is in a simulator which has the possibility for comparing simular engagements in which these cues are provided with those in which the cues are eliminated.

#### 4.9.4.9 Areas of Greatest Information Return

Another use of simulator in planning for a live test is to identify those regions of greatest information return for the resources expended. Regions of Greatest Information Return: Example: Air Combat Testing. Problem: US has no Foxbats against which to fly F-15, F-14. Not much uncertainty of outcome (and thus not much information) in tests of F-14 and F-15 vs. F-5E. Simulation Approach: Validate simulator by comparing F-5E encounters with F-15, F-14 in simulator, with live tests. Then: Use simulator to "fly" F-15, F-14 (with various advanced armament) against Foxbat. We may look at this aspect either from the information theory approach or simply from the viewpoint of common sense. Information theory tells us that in any experiment, the greatest

information return occurs when we have *a priori* uncertainty about the outcome. From a common sense point of view we might simply note that if we can predict with high confidence the outcome of the experiment in advance, there's not much need to perform the experiment to begin with. Probably not many readers have very much uncertainty in their own minds of the outcome of an air combat battle which pits F-15s or F-14s against F-5Es. Thus, the information return of such a test is likely to be low. One of the objectives of the current testing is to determine which type of dogfight missile should be procured for the F-15 and the F-14 in the future. One conceivable outcome of the test is that either an F-15 or an F-14 is capable of shooting down an F-5 with nothing more sophisticated than a 20mm gun, and therefore, neither service needs a new dogfight missile. Obviously, what is needed for the current testing is a more credible threat aircraft against which to fly the F-14 and F-15, than the F-5E. The problem, of course, is that no such threat aircraft is available in the United Sates, at least not now. Therefore, an approach to mitigate this problem using a simulator is to go ahead and run encounters between F-14s and F-5Es and F-15s and F-5Es, and validate the credibility of the simulator by comparing the same kind of tests in a simulator with those conducted live. Then use the simulator to fly those same U.S. aircraft against a Foxbat or some other more credible and contemporary enemy aircraft. The results of such a test, even though they are less that what we would desire, (i.e., a live test with credible threat aircraft) at least have a better chance of showing the requirements for a dogfight missile than a live test which pits the current generation of U.S. interceptors against an approximation of the previous generation of enemy aircraft.

#### 4.9.4.10 Effects of Uncontrolled Variables

Another use of simulators is to estimate the possible deleterious effect the influence of uncontrollable variables introduces in the live test. One of the problems for AIMVAL/ACEVAL is that the missiles to be employed in the AIMVAL test are prototype research and development missiles, for which no tactics have been

developed, taught and practiced by the crew which will be involved in the test. Therefore, it takes very little prophecy to suggest that there will be a pronounced learning effect during the course of the test, since there will be very little prior experience either in the tactics which should be employed to exploit the technical characteristics of these advanced missiles or in the training and practice of these tactics after they have been developed. Obviously a simulator could be used to familiarize crews with the technical options that are made available by the characteristics of these advanced missiles, at least in one-on-one and two-on-one situations. Obviously, the simulators that we have available today (which cannot present two-on-one or two-on-four situations) will not be able to assist in the development of more complicated tactics which take advantage of the greater numbers of participants. However, it does seem that we should take advantage of the simulators that are available to familiarize the crews with the various technical options, at least in the simpler situations of these advanced missiles. By so doing, we can expect that some portion of the steep section of the learning curve can occur in the simulation, rather than to incur the confounding effect of the total learning curve during the live test.

#### 4.9.4.11 Conclusion

These examples lead to the indicated conclusion: Opportunity exists for better exploitation of simulators in the context of operational tests:

a. Use simulators to aid test design.

b. Design and execute tests with validation of simulators as an explicit objective.

c. Use validated simulator to extend test results beyond conditions of live test.

There certainly exists an opportunity to better exploit the simulators that we have available to us, in the context of the relationship to operation tests. By that, it is mean that 1) There is better opportunity to

use simulators in test design and test planning, 2) That tests should be designed and executed with the validation of simulators as an explicit test objective in addition to those principle objectives of the test, in order that 3) Validated simulator results may be used to extend the test results beyond those conditions which are possible in a live test situation.

#### 4.9.5 Miscellaneous Support Items

In range operation and maintenance substantial support is available from other agencies. Further, the interaction of range operations with completely unrelated activities, particularly, in respect to environmental matters must be given full consideration. The subject of general facilities, including those not directly related to the technical aspects of test is also a very important one. These items will be considered in the following subsections.

#### 4.9.5.1 Radar Emission Spectrum and Antenna Measurements

#### 4.9.5.1.1 General

The objective of Electromagnetic Qualification measurement field support is to provide the Air Force and other DOD and government agencies the capability of accurately determining the actual electromagnetic characteristics of any given radar system under operational conditions. Utilizing the RATSCAT (Radar Target Scatter Division) at Holloman AFB, New Mexico, the user and/or developing agencies can obtain an independent Air Force assessment of contractor delivered equipment and its operation and maintenance.

#### 4.9.5.1.2 Requirements

The data collection requirement for field measurement support is the provision to range operators of a capability not found in-house to maintain; validate and calibrate electromagnetic radiating equipment. Data collected may also be used for electromagnetic compatibility assessments, intelligence validations, maintenance data base generation, and bench O&M justifications.

4.9.5.1.3 Data Collection Parameters

Equipment data collection parameters and techniques are described in MIL-STD-449D, and in general, include:

a. Time, waveform and RF power.

b. Conducted emission spectrum.

c. Radiated emission spectrum.

d. Antenna patterns.

e. Receiver sensitivity parameters.

These parameters may be varied depending upon field measurement requirements.

4.9.5.1.4 Recommendations

The Radar Target Scatter Division (RATSCAT) at Holloman AFB, New Mexico, has a proven capability to conduct the measurements program at OTT&E ranges. Support required should be planned and coordinated with RATSCAT well in advance so contract, equipment, and personnel actions can be taken in a timely manner. The assessment data closes the gap between radar designers, developers, and users. The field measurements program also identifies deficiencies in radar technical manuals.

4.9.5.2 Air Traffic Control and Air Space Management

Air Traffic Control services for aircraft on USAF gunnery, weapons and test ranges are a fairly new concept to the managers of USAF Air Traffic Control Resources (Air Force Communications Service). Air Traffic Control or the control of aircraft traveling to and from ranges gained impetus in the last five years as mandatory Instrument Flight Rules (IFR) flights became a way of life in the Air Force. Tied to this was the rapid growth of Civil/General aviation and the need for more freedom of movement in the already greatly restricted airspace for the civil user and a requirement

for a larger portion of the airspace for the testing and development of new weapons systems for the Department of Defense.

Numerous attempts have been made by the Air Force to make better use of the airspace they already control on a part time or full time basis by taking formerly Restricted Airspace and converting it to Joint use airspace for better utilization by all civil and military users.

4.9.5.2.1 Basic Considerations

a. Airspace requirements and current Air Traffic density should be properly considered when a new range location is picked or existing range capabilities are increased. Safety and environmental considerations associated with airspace use should be major inputs prior to any major decisions or new range locations or improvements to existing ranges.

b. Once a range is established and it is determined that Air Traffic Control Services are desired or required the controlling agency must check for conflicts with other air traffic; i.e., General Aviation Flyways, Airways, Airports, Low Altitude-High Speed Routes, Airstrips (private), and other possible constraints to determine what Air Traffic service would do to these users.

c. Equipment is required to ehhance the joint use of airspace: proper radar coverage; adequate radios; landline communications; and properly trained Air Traffic Controllers along with the facilities in which to locate the men and equipment. These resources should be included in the long term planning, programming and budgeting cycle.

4.9.5.2.2 Operations

In the interest of realism and as safety permits, mission aircraft, once on the range, will be allowed maximum freedom of movement to complete the mission. In this respect the Air Traffic Control facility will be

required to work closely with the manager of the range in mission scheduling so no one portion of the range has conflicts or saturation while other segments are not being used. In addition to the range users requirements in scheduling, consideration must be given to the civil users' needs and above all, the reason for Air Traffic Control, safety of all users.

4.9.5.2.3 Coordinating Agencies

The agencies listed below are involved in airspace and air traffic management and can provide Air Traffic Service to his operation.

a. Headquarters Air Force Communications Service/ DCS Flight and Airspace Management.

b. HQ USAF/XOOF

c. The Air Force Representative at the nearest FAA Region (this officer is a member of the Air Staff (XOOF)).

d. DOD Flight Information Publication (FLIP), Area Planning Special Use Air Space.

4.9.5.3 Weather Prediction Use

Staff meteorological support is provided to AFSC ranges by the 6th Weather Wing, with headquarters at Andrews AFB, Maryland. Supporting the range detachment is the Environmental Tactical Applications Center (ETAC), which is a studies and analysis center located in Asheville, North Carolina, and in the Washington Naval Yard. Another important source of environmental data is the Cambridge Research Laboratory. If a staff meteorologist cannot solve a problem, an analysis will be performed by one of these two organizations.

4.9.5.3.1 Meteorological Impact

Since clouds cover about 50% of the world at any given moment, they represent the most significant meteorological impact on range operation. Severe weather

phenomena are more easily recognized and range operations curtailed accordingly. Clouds in general, however, can impact range operations by restricting visibility (visual), radar electro-optics, infrared), limiting flying operations (turbulence, rain, icing), and disrupting communications (lightning, spacious deflections).

4.9.5.3.2 Forecast Usage

A study done by the systems command at ESD called Weather 85 proposed three approaches to weather problems. 1) Engineer it out and achieve a truly all weather Air Force. 2) Modify the weather. 3) Improve the use of weather information. The first is probably a physical impossibility. The laws in physics would have to be changed to do some of the things necessary to call a weapon "all-weather." In weather modification, there is good progress in cold fog dissipation. There is now an effort underway at CRL for a new warm fog dissipation system. It also has promise in weather modification, however, it takes a particular kind of situation that is amenable to modifications. The third possibility - improve the use of weather information, is an area in which program can be made with present technology. Figure 4-42 shows the deterioration of a forecast over time. It shows that a weather observation is perfect and that is is approximately true (99.5% level). In this time period (high side of the curve), something like 0 to 20 minutes, the forecaster is generaly accurate. Out in the 24 to 36 hour time period, he is not so good. To improve the use of weather information in decision making, compress the time of decision -- "Time of Weather Observation and Time of the Forecast." Along this curve to the left, is the engineering approach. It is contrasted to the scientific approach in the vertical. Improve meteorology, or raise this curve in the vertical, by improving the state-of-the-art. This is what the Cambridge Research Laboratory has been concentrating on for years. The engineering approach is known as time compression. To complement that, to make sure the data is available that is necessary to give the decision maker what he needs, there must be another

DECAY OF UTILITY OF WEATHER INTELLIGENCE

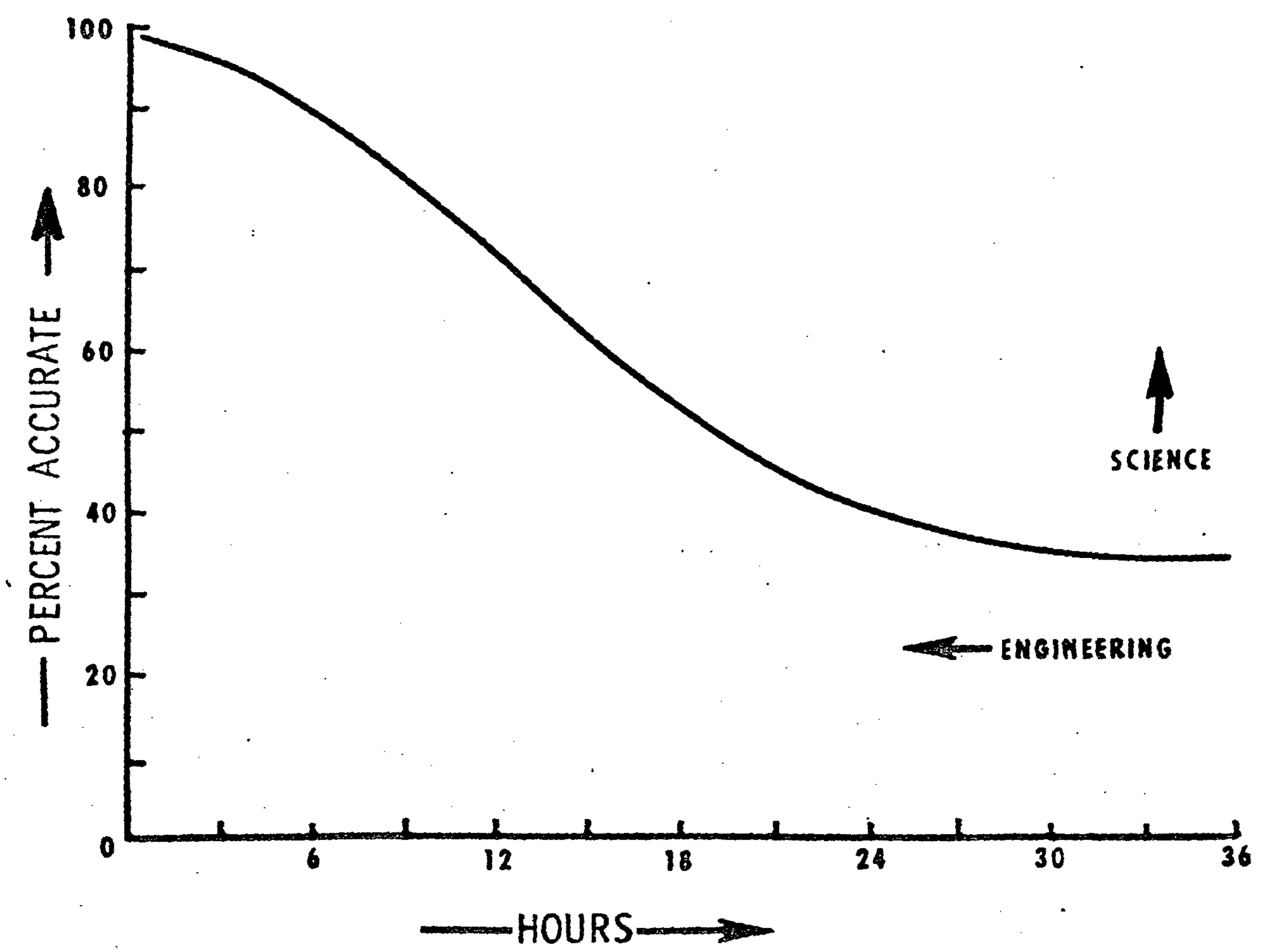
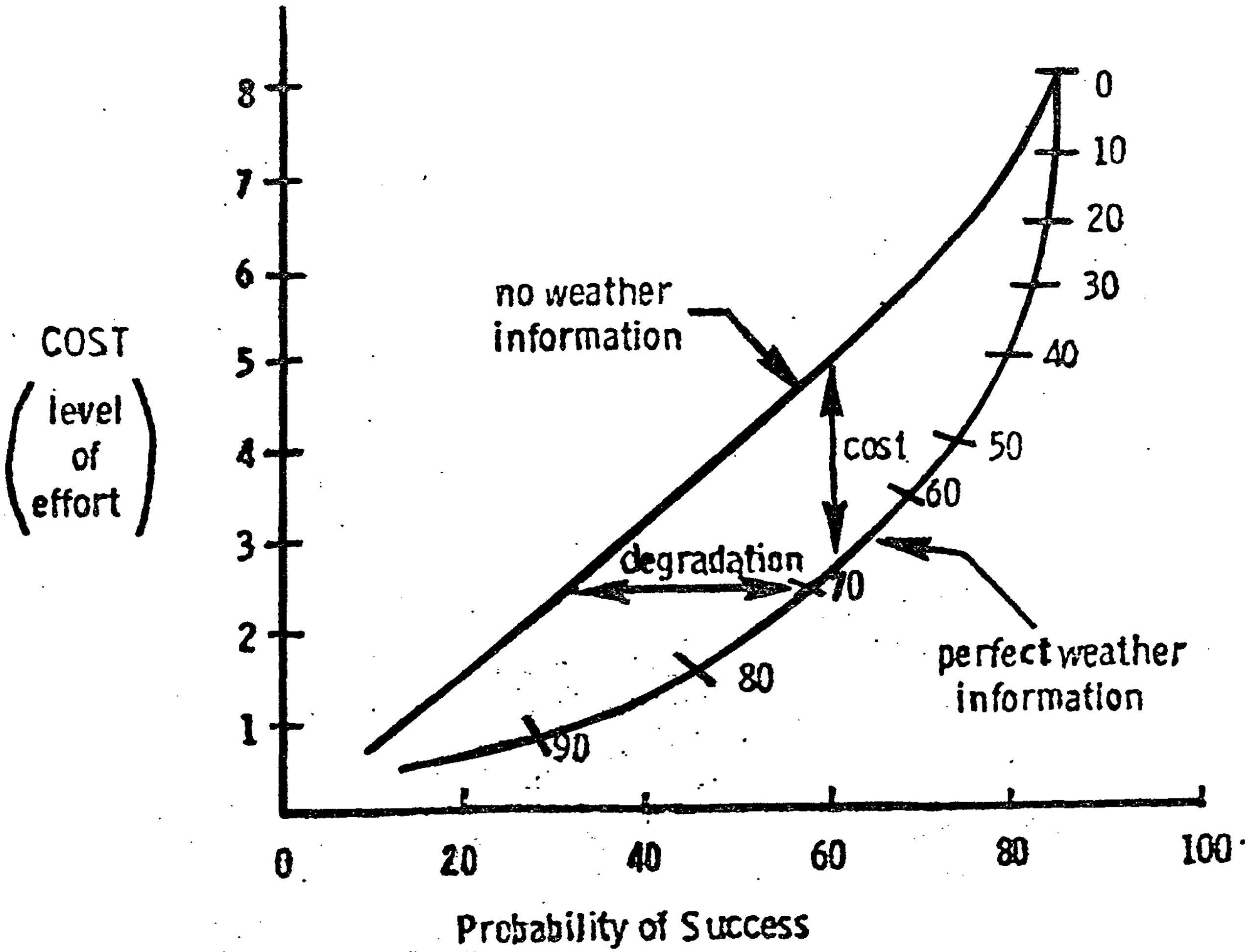



FIGURE 4-42

kind of information - known as the operating characteristics. Figure 4-43 shows in terms of cost and probability of success in any given event. What happens without weather information or climatology is shown by the No Weather Information line. If the operating characteristics are known, we can calculate by observing test characteristics in the environment and present to a commander, the decision maker, numbers that say if willing to commit (for example) on a 70% threshold, then over a long period of time he will succeed about 50%. If not, then on the no-weather curve, the cost will increase by about a factor or two and probability of success over a longer period of time will be degraded.

To develop decision algorithms that integrate probability of success with other data that helps a commander make a decision, we need to know (for a tactical scenario) the target, the base location, characteristics, the degree of difficulty, and the priority. We know the resources, such as aircraft, weapon mis, pilot, that sort of thing. Marry this with the probability of success indicator that can be provided by developing the operating characteristics and you then have potentially a closed system that will match the weather, probability of success, target, aircraft, weapon, tactic or anything else you want. To do that job are two key needs the necessary data, and a command and control system to put it in. Ceiling and visibility are not the only problem in solving a target acquisition problem for a precision guided munition. There are other things, like target contrast, time of day, reflectance, for which there are no measurements taken today. In a case of war, the only weather data is ceiling and visibility. What are needed are the empiricims that if clouds and visibility under certain air mass conditions are known, an inference can be made of probability of success by knowing the operating characteristics of the weapon.

A second need is a better emphasis on command and control, that is, compressing the time from which data are gathered and the time when the decision is made. That doesn't only apply to weather data, but to intelligence, logistics, personnel, or anything else, when




**FACTORS**

- TOTAL RESOURCES
- ADVERSE WEATHER EFFECTIVENESS
- CLIMATOLOGY
- DECISION MECHANISM and INPUTS

Figure 4-43

working in a time sensitive environment, with some of the things that are envisioned in WWMCCS and 485L. Any data that are perishable and need to be compressed will require automation, computer transmission of data and the integration into the decision algorithm.

4.9.5.3.3 Recommended Weather Instrumentation

| Obsevation | Device |
|---|---|
| Standard Obs | AWS Observation |
| Visibility | Integrating Nephelometer |
| Turbidity | Sunphotometer |
| | Pyrheliometer |
| Light Level | Pyranometer |
| | Photometer |
| Cloud Cover | All Sky Camera |
| Rainfall Rate | Rain Guage |
| | Recording Devices |
| | Power Converters |
| | Expendables |
| | Total |

4.9.5.4 Environmental Statement (ES)

An environmental assessment must be made for the overall range operation and include foreseen improvements and an environmental statement prepared and filed if required. Other agencies and appropriate contractors should be tasked for technical support as required. After filing the initial ES with the Council on Environmental Quality (CEQ), update assessments must be made and statements filed, where required, not less than annually during range development. Notwithstanding, the environmental consequences of any proposed action will be assessed at the earliest practical stage in the planning process, and in all instances prior to decision. Environmental assessments and statements (updates) will be prepared in accordance with guidelines issued by HQ USAF and the latest Federal Regulation. The environmental statement should include a detailed description of the proposed action, the relationship of the proposed action to existing land use plans and policies, probable impacts of the proposed action; and

alternatives to the proposed action. The Environmental Statement for Proposed Continental Operations Range dated 17 December 1974 is a very extensive and thorough statement and could be used as a guide.

4.9.5.5 Facilities

Since facilities are a long-lead item, it is very important that the requirements be determined and the programming started early.

4.9.5.5.1 Civil Engineering Concept

Civil Engineering methods and procedures to be implemented during development, acquisition and follow-on maintenance of a range are discussed in this section. Facilities to include utilities support are long lead items. They can be obtained in several ways with both type of work and dollar cost critical to funding category and lead time. Also, real estate rights and environmental effects are key factors and must be considered and resolved at the earliest practical stage in the planning process. The Base Civil Engineer (BCE) with the real estate records for the range is normally the focal point for all Civil Engineering actions. BCE procedures are prescribed and the range is normally a remote portion of his primary base workload.

a. Operational Facility Concept. It is to be anticipated that range development or improvement will jointly use facilities servicing other systems. Maximum utilization of existing facilities must be made. Facilities required are those necessary to support, house, store and secure system, equipment and personnel requirements. Emphasis should focus on equipment mobility whenever mission requirements can be met cost effectively.

b. Management Concept. As facility requirements are validated, it is necessary to fund these projects using O&M minor construction funds, emergency or routine Military Construction Program (MCP) funds, emergency minor construction (P-341) funds, or RDT&E funds (AFR 80-22) dependent upon lead time. Preparation of programming documentation will be accomplished through the Base

Civil Engineer in accordance with AFM 86-1, Programming Civil Engineer Resources, and related Air Force/Service policies. A separate range Facilities Working Group (FWG) should be established and chaired by a range representative. This FWG will provide scoping reviews, review facility programming actions, and act as a facilities coordinating group and sounding board for all range facility actions and recommend to the Base Facilities Board. Standard Air Force facility (AFM 88-2, Definition of Air Force Structures) or Bare Base System Segment Designs should be used to the greatest extent possible. Facility alteration or construction projects will be designed in accordance with applicable Air Force/Host Command policies; e.g., AFM 88-15, Air Force Design Manual Criteria and Standard of Air Force Construction, etc. Facility alteration or construction projects will be executed by the designated agency--Army Corps of Engineers, Navy Facilities Engineering Command, Air Force Major Air Command, or local Base Civil Engineer. Real property facilities may be used by Air Force personnel prior to final completion in accordance with AFR 85-17, Beneficial Occupancy. Final acceptance and transfer of real property will be accomplished in accordance with AFR 88-9, Transfer and Acceptance of Facilities Constructed for the Air Force. Normal maintenance functions are funded and performed by the local Base Civil Engineer starting at the fime of Air Force beneficial occupancy of the facility. When another command (e.g., AFSC) becomes an interim user of the real property pending installation of system equipment, facility repair, and normal maintenance or modification will be arranged for through the Base Civil Engineer. Facility maintenance practices required for facilities determined to be unique or to contain complex facility subsystems will be formulated by a range operator and approved by the Facilities Working Group.

c. Range Facility Master Plan. A Range Facility Master Plan should be prepared and maintained for the range as part of the Civil Engineering Plan in coordination with the BCE.

## 4.9.5.6 Mapping, Charting and Geodesy (MC&G)

MC&G products include maps, charts, target materials, digital terrain and point positioning data bases, radar simulation plates and data files, correlation matrices and geophysical data. Services include evaluation of the above data, geodetic positioning, instrumentation calibration, positioning and related activities. Detailed descriptions and procedures for obtaining support are contained in AFR 96-9.

Long range planning and programming for use of required Defense Mapping Agency resources are required. DMA offices are DMA-AC, St Louis AF Station, St Louis, Missouri 63118 and DMA-AC, F. E. Warren AFB, Wyoming 82001. The DMA-AC/PR Air Force contact is currently Major Frank Hotter, St Louis AFS, Missouri 63118, AV 698-4871.